THE ANATOMY OF THE EYE AND ORBIT

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Including the central connections, development, and comparative anatomy of the visual apparatus

BY

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TO

PERCY FLEMMING

PREFACE TO THE SECOND EDITION

The appearance of a *second edition of this Anatomy of the Eye and Orbit* has enabled me to make several corrections and to add some sixty illustrations, the majority of which were prepared from sections made in the Pathological Laboratory at the Royal Westminster Ophthalmic Hospital

Included in these pictures is a series of flat sections of the retina, without which it is quite impossible, I think to get a proper idea of the structure of this membrane

Among other changes, the blood supply of the visual pathway has been rewritten, there is a note on the differential staining of the rods and cones, and something new about the structure of vessels of the iris

I am much indebted to Professor H A Harris who kindly corrected the proofs and made many useful suggestions, to the Royal Society of Medicine and the Ophthalmological Society of the United Kingdom for figures published in the Proceedings and Transactions respectively, to Mr Pittock and Mr McDonald for the photo micrographs, and to the Publishers, who have again done their utmost to carry out my wishes

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PREFACE TO THE FIRST EDITION

This Anatomy of the Eye and Orbit is based mainly on lectures and demonstrations which I have had the honour to give during ten years as Demonstrator of Anatomy at University College, and for the last three years as Pathologist and Lecturer in Anatomy to the Royal Westminster Ophthalmic Hospital

It is an attempt to present to the Student and Ophthalmic Surgeon the essentials of the structure, development and comparative anatomy of the visual apparatus in conjunction with some of their clinical applications The motor nerves to the eye muscles have received special attention, as have also the illustrations, many of which are from my own preparations

My indebtedness is manifold to my chief Professor Elliot Smith, who has given me much advice and help, especially in the portion dealing with the neurology of vision , to Dr H A Harris for many useful suggestions , to Mr Percy Flemming, who first taught me to combine Anatomy with Ophthalmology , to Sir John Parsons, to whom I owe many points in applied Anatomy , to the Surgeons of the Royal Westminster Ophthalmic Hospital for help and encouragement , to the artists who have done their work with so much skill and care , to my wife, who aided me in many ways , and to the Publishers, who have tried their utmost to carry out my wishes

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ANATOMY OF THE EYE AND ORBIT

CHAPTER I

THE BONY ORBIT AND ACCESSORY SINUSES OF THE NOSE

The Bony Orbit

The two orbital cavities are placed on either side of the mid vertical line of the skull between the cranium and the skeleton of the face Thus situated they encroach about equally on these two regions (Winckler)

Above each orbit is the anterior cranial fossa medially are the nasal cavity and air sinuses below is the antrum of Highmore, while laterally from behind forwards are the middle cranial and the temporal fossæ

The orbit is essentially intended as a socket for the eyeball but also contains the muscles, nerves and vessels which are essential for its proper functioning Moreover, it serves to transmit certain vessels and nerves destined to supply the areas of the face around the orbital aperture

Seven bones take part in the formation of the orbit, namely the superior maxilla and palate, the frontal the sphenoid and malar or zygomatic bone, the ethmoid and the lacrimal bone

The orbit has *roughly* the shape of a quadrilateral pyramid whose base, directed forwards, outwards and slightly downwards, corresponds to the orbital margin, and whose apex is the optic foramen or, as some hold, the inner end of the sphenoidal fissure, or the bar of bone between these two apertures (Whitnall)

As stated above, the comparison with a quadrilateral pyramid is a rough one only, for since the floor (which is the shortest orbital wall) does not reach the apex, the cavity is triangular on section in this region

Also, since the orbit is developed around the eye, and is bulged out by the lacrimal gland, it has a tendency towards being spheroidal in form, and its widest part is not at the orbital margin but about 1 5 cm behind this Moreover, this results in the fact that its four walls are for the most part separated from each other by ill-defined rounded borders, so that Whitnall compares the shape of the orbit to a pear whose stalk is the optic canal It is important to note that the inner walls of the orbits are almost parallel, whereas the outer walls make an angle of about 90° with each other The direction of each orbit is given by its axis which runs from behind forwards, outwards and slightly downwards

The roof or vault of the orbit is triangular in shape It is formed in great part

by the triangular orbital plate of the frontal bone and behind this by the lesser wing of the sphenoid It does not look directly downwards but slightly forwards as well It is markedly concave anteriorly and more or less flat posteriorly The anterior concavity is greatest about 1 5 cm from the orbital margin and corresponds to the equator of the globe

It presents

(a) *The fossa* for the lacrimal gland This lies behind the external angular process of the frontal bone It is simply a slight increase in the general concavity of the anterior and outer part of the roof, and is better appreciated by touch than by sight It contains not only the lacrimal gland but also some orbital fat found principally at its posterior part (accessory fossa of Rochon Duvigneaud) It is bounded below by the ridge corresponding to the zygomatico frontal suture at the junction of roof and lateral wall of the orbit It is usually quite smooth, but may be pitted by the attachment of the suspensory ligament of the lacrimal gland when this is well developed

(b) *The fovea* for the pulley of the Superior oblique is a small depression situated close to the internal angular process some 4 mm from the orbital margin (Figs 1 and 2) Sometimes (10 per cent) the ligaments which attach the U shaped cartilage of the pulley to it are ossified Then the fossa is surmounted most often posteriorly by a spicule of bone (the *Spina trochlearis*) Extremely rarely a ring of bone, representing the trochlea completely ossified, may be seen (Winckler)

(c) *The fronto sphenoidal suture*, which is usually obliterated in the adult, lies here between the orbital plate of the frontal bone and the small wing of the sphenoid

The roof of the orbit is separated from the inner wall by fine sutures between the frontal bone above and the ethmoid, lacrimal, and frontal processes of the superior maxilla below In or just above the fronto ethmoidal suture are the anterior and posterior ethmoidal canals (Figs 1 and 2) (see later) The roof is separated from the lateral wall posteriorly by the superior orbital (sphenoidal) fissure, anteriorly by the slight ridge that marks the fronto zygomatic suture The orbital aspect of the roof is usually quite smooth but may be marked by certain small apertures and depressions The apertures known as the *Cribra orbitalia of Welcker* are found most commonly to the inner side of the anterior portion of the lacrimal fossa They are not always present and are best marked in the fœtus and infant (Winckler) They give the bone a porous appearance and according to Toldt, are for veins which pass from the diploë to the orbit

In the posterior part of the orbit, in or around the outer part of the small wing of the sphenoid small orifices may also be found which serve as communications between the orbit and the cranial cavity and contain vessels during life

Numerous small grooves may be seen in the roof of the orbit These lead to the above orifices and are made by vessels or nerves

Very rarely one may find an antero posterior fissure up to 14 mm long filled with periorbita and dura mater

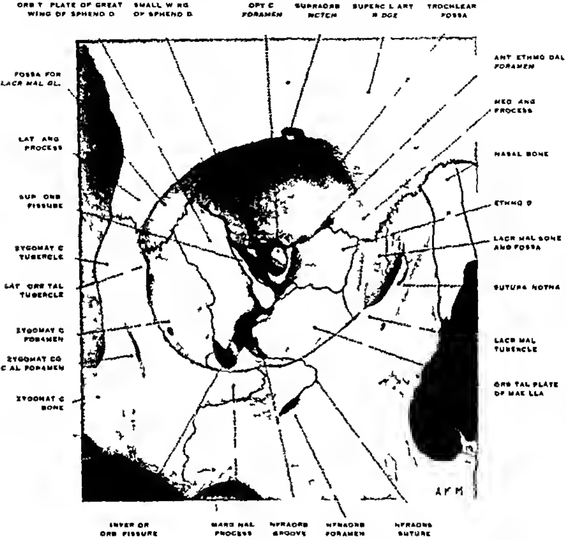

Fig 1 —The Orbit from in Front

Structure —The roof of the orbit is very thin translucent and fragile except where it is formed by the small wing of the sphenoid which is 3 mm thick If the bone be held up to the light, one can make out the ridges and depressions on the cranial aspect formed by the sulci and gyri of the frontal lobe of the brain This is especially true of the posterior two thirds The translucency of the anterior third varies, and depends on the extension of the frontal sinus into the roof of the orbit

Often in old age portions of the bone may be absorbed, and then the periorbita is in direct contact with the dura mater of the anterior cranial fossa It

is quite easy, in the disarticulated skull, to break the roof of the orbit by slight pressure with the finger

Also punctured wounds through the lids are sometimes inflicted with the points of umbrellas or walking sticks, and the roof of the orbit may easily be fractured by direct violence (Fisher)

The roof of the orbit is invaded to a varying extent by the frontal sinus and sometimes by the ethmoidal air cells The frontal sinus may extend outwards to the external angular process and backwards close to the optic foramen The ethmoidal air cells not infrequently invade the lesser wing of the sphenoid

Relations—The frontal nerve lies in direct contact with the periorbita for the whole extent of the roof (Figs 143 and 144) The supraorbital artery accompanies it only in the anterior half Beneath the nerve is the levator palpebræ, and deep to this again is the superior rectus

The lacrimal gland occupies the lacrimal fossa and the superior oblique lies at the junction of the roof and the medial walls

Invading the roof to a variable extent as seen above, are the frontal sinus and the ethmoidal air cells

Above the roof are the meninges covering the frontal lobe of the brain

The inner wall of the orbit (Fig 2) is the only wall which is not obviously triangular It is roughly oblong either quite flat or slightly convex towards the orbital cavity It runs parallel with the median plane and consists from before backwards of four bones united by vertical sutures

(*a*) The frontal process of the superior maxilla
(*b*) The lacrimal bone
(*c*) The lamina papyracea (os planum) of the ethmoid
(*d*) A small part of the body of the sphenoid with sometimes (*e*) the sphenoidal turbinated bone

Of these the lamina papyracea of the ethmoid takes by far the largest portion It often shows a characteristic mosaic of light and dark areas The dark areas correspond to the ethmoidal air cells while the light lines between them correspond to the partitions between the cells

In the anterior part of this wall is the *lacrimal fossa* formed by the frontal process of the superior maxilla and the lacrimal bone It is bounded in front and behind by the *anterior* and *posterior lacrimal crests* Above there is no definite boundary, while below the fossa is continuous with the bony naso lacrimal canal At their point of junction the hamulus of the lacrimal bone curves round from the posterior to the anterior lacrimal crests and bounds the fossa to the outer side (Fig 2)

At this point the fossa is some 5 mm deep while it gradually gets shallower as we trace it upwards It is about 14 mm in height The lacrimal bone and frontal process of the superior maxilla take varying parts in the formation of the fossa, and so the position of the vertical suture between them varies also

The anterior lacrimal crest on the frontal process of the superior maxilla is ill defined above but well marked below, where it becomes continuous with the lower orbital margin and here often presents a *lacrimal tubercle* (Fig 1)

The upper half of the fossa is in relation to anterior ethmoidal air cells the lower part to the middle meatus of the nose (see also p 159)

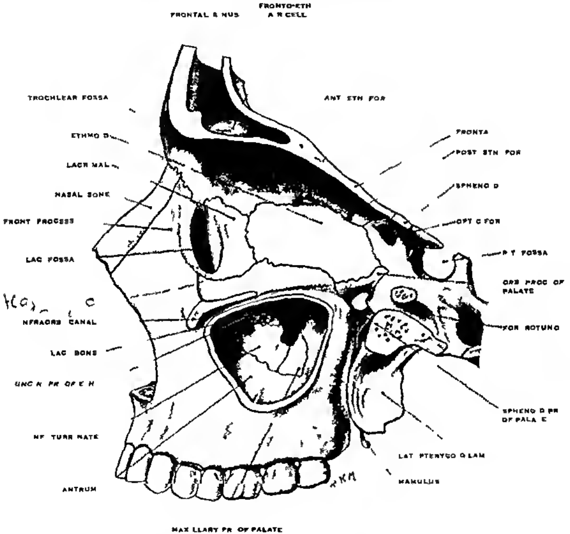

FIG 2 —THE MEDIAL WALL OF THE ORBIT

The Structure of the Inner Wall —The inner is by far the thinnest orbital wall (0 2–0 4 mm) It is translucent so that if held up to the light, the ethmoidal air cells can be plainly seen

The lamina papyracea of the ethmoid as its name implies is in fact, as thin as paper, and infection from the ethmoidal air cells can easily get into the orbit *This is the reason why ethmoiditis is the commonest cause of orbital cellulitis*

Despite its thinness, however, the lamina papyracea but rarely shows senile absorptive changes, whereas the thicker lacrimal bone, especially that portion which enters into the formation of the lacrimal fossa, is often absorbed. Indeed, it is rare to find an adult skeleton with a whole lacrimal bone.

VARIETIES.—The lacrimal bone may be divided by accessory sutures into several parts (Schwegel, Henle, Hyrtl).

A Wormian bone may be developed in its upper and forepart.

An accessory lacrimal bone, such as is found in many lower animals, may be split off the front of the ethmoid.

The hamulus may be absent, may exist as a separate bone, or may be double.

Relations.—The ethmoidal air cells are in relation to the lamina papyracea and to the lacrimal bone. Posteriorly the sphenoidal sinus also is in relation to this wall (Fig. 3).

The superior oblique occupies the angle between the roof and medial wall, and the internal rectus runs along this wall, while between the two muscles are the naso-ciliary nerve and the termination of the ophthalmic artery (Fig. 144).

Anteriorly the lacrimal sac lies in its fossa, surrounded by the lacrimal fascia, while just behind it is the attachment of Horner's muscle, the septum orbitale, and the check ligament of the medial rectus (Figs. 112 and 113).

The floor of the orbit is roughly triangular, corresponding to the shape of the roof. It is not quite horizontal, but slopes slightly downwards from the medial to the lateral side. The lowest part of the floor of the orbit is found in a concavity some 3 mm. deep at the outer and anterior part. The floor (47.6 mm. long), the shortest of the orbital boundaries, is formed by three bones:

(1) The orbital plate of the *superior maxilla*.
(2) The orbital surface of the *zygomatic* (*malar*).
(3) The orbital process of the *palate bone*.

Of these the *superior maxilla* takes by far the largest portion. The *zygomatic* forms the antero-lateral part, while the *palate bone* occupies a small area behind the maxilla. The sutures between the three bones forming the floor of the orbit are almost invisible.

The floor of the orbit is traversed by the *infraorbital sulcus*, which runs almost straight forwards from the inferior orbital (spheno-maxillary) fissure. At a variable distance (usually about half-way) it is converted into a *canal* by a plate of bone which grows over it from its *lateral* side to meet the medial in a suture (the infraorbital suture), which is but rarely obliterated (Fig. 3). This suture can be traced over the lower orbital margin to the medial side of the infraorbital foramen (Fig. 1).

The infraorbital canal, formed as described above, sinks anteriorly into the orbital floor and opens at the infraorbital foramen some 4 mm. from the orbital margin. It transmits the infraorbital vessels and nerves. Along its course it

gives off the *middle* and *anterior superior alveolar (dental) canals*, for the corresponding nerves and vessels

Lateral to the opening of the naso lacrimal canal a small pit or roughness marking the origin of the inferior oblique muscle may (rarely) be found

The floor of the orbit is separated from the medial wall only by a fine suture,

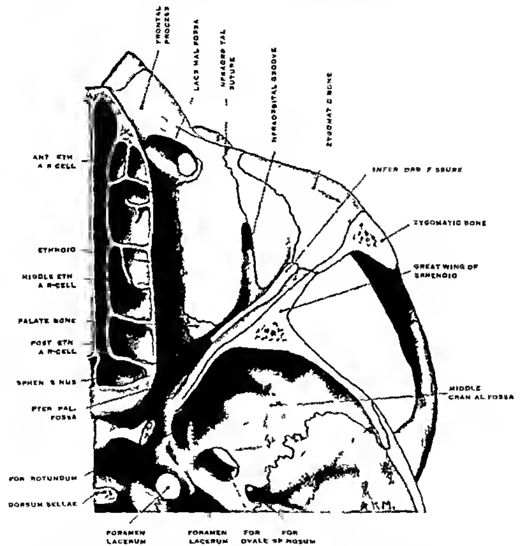

FIG 3—THE FLOOR OF THE ORBIT

the lateral wall is separated from it posteriorly by the inferior orbital (spheno maxillary) fissure while anteriorly it is continuous with it (Fig 3)

VARIETIES—Not infrequently the roof of the infraorbital canal and sometimes its floor may be incomplete but otherwise only very rarely does the floor of the orbit show holes, the result of senile absorption Langer has seen three cases where the infraorbital canal ran in the suture between the superior maxilla and the malar bone

Relations and Structure.—*Below* the floor of the orbit for nearly its whole extent is the antrum of Highmore, a most important practical relation. *For as the bone between them is only 0·5—1 mm. thick, tumours of the antrum can easily invade the orbit, causing proptosis.*

More posteriorly is the air-cell inside the orbital process of the palate bone, and sometimes extensions from the ethmoidal air-cells may invade the floor.

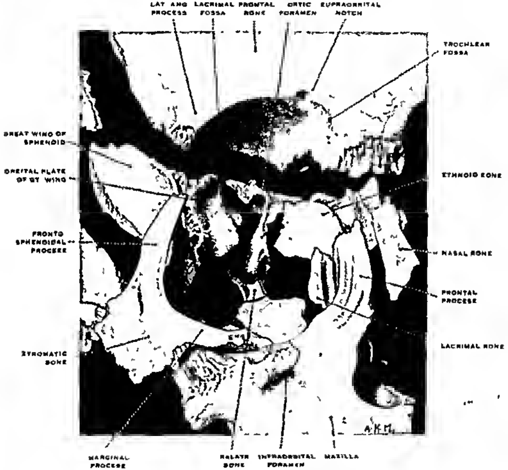

FIG. 4.—THE BONES OF THE ORBIT IN SITU BUT SEPARATED

The inferior rectus is in contact with the floor near the apex of the orbit, but anteriorly it is some distance away, being separated from it by the inferior oblique muscle and some fat. Lateral to the inferior rectus and lying on its lateral edge or between it and the external rectus is the nerve to the inferior oblique (Fig. 147).

The inferior oblique arises just lateral to the opening of the naso-lacrimal

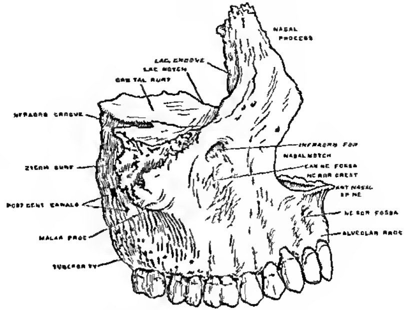

FIG 5 —RIGHT SUPERIOR MAXILLA (OUTER VIEW)
(*From Quain's Anatomy*)

canal and passes backwards, outwards, and upwards for the most part near the floor (Fig 142)

The infraorbital vessels and nerve lie in the infraorbital sulcus and canal

The outer wall of the orbit is triangular *in* shape, the base being anterior It makes an angle of 45° with the median sagittal plane and faces inwards, forwards and slightly upwards in its lower part It is slightly convex posteriorly, flat at its centre, while anteriorly the orbital surface of the malar 1 cm behind the orbital margin is concave

The outer wall of the orbit is formed by two bones

(*a*) Posteriorly by the orbital surface of the great wing of the sphenoid

(*b*) Anteriorly by the orbital surface of the zygomatic (malar) bone

The sphenoidal portion is sharply separated from the roof and floor by the superior and inferior orbital fissures respectively

The zygomatic portion passes imperceptibly into the floor, and is separated from the roof by the fronto-zygomatic suture, which is roughly horizontal and often marked by a slight ridge The suture between the two portions of the outer wall is vertical (Fig 1)

The outer wall presents

(1) *The Spina recti lateralis* of Merkel —This is a small bony projection situated on the inferior margin of the superior orbital fissure at the junction of its wide and narrow portions It may be pointed, rounded, or grooved, and gives origin to a part of the external rectus muscle, but it is produced mainly by a groove which lodges the superior ophthalmic vein This groove is prolonged upwards, then runs anterior to the spine Not infrequently the spine is duplicated

(2) *The Zygomatic Groove and Foramen* —The groove which lodges the

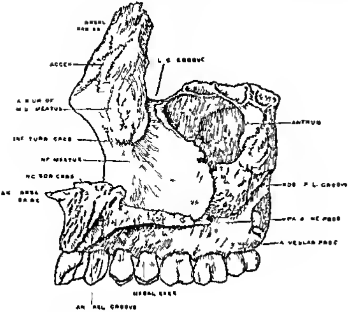

FIG. 6.—RIGHT SUPERIOR MAXILLA (INNER VIEW)

(From Quain's "Anatomy")

nerve and vessels of the same name runs from the anterior end of the inferior orbital fissure to a foramen in the malar bone. This leads into a canal which divides into two, one branch opening on the cheek, the other in the temporal fossa. Thus the branches of the zygomatic nerve reach their destination. If the nerve divides before entering its canal, there may be two or even three grooves and foramina in the orbit.

(3) *The Lateral Orbital Tubercle* (Whitnall)[1].—This is a small elevation on the orbital surface of the zygomatic bone just within the outer orbital margin and about 11 mm. below the fronto-zygomatic suture. It gives attachment to

(a) The check ligament of the lateral rectus muscle.

(b) The suspensory ligament of the eyeball.

(c) The lateral palpebral ligament.

(d) The aponeurosis of the levator palpebræ superioris (Fig. 142).

The conjoined attachment of these four structures forms the lateral ocular retinaculum of Hesser.

FIG. 7.—RIGHT PALATE BONE (FROM BEHIND)

(From Quain's "Anatomy")

(4) Not infrequently there is a foramen in or near the suture between the great wing of the sphenoid with the frontal, near the outer end of the superior

[1] Whitnall, *Journ. of Anat. and Phys.*, 1911, xlvi, p. 36.

orbital fissure This leads from the orbit to the middle cranial fossa and transmits a branch of the meningeal artery and a small vein (Testut)

Structure—Being the one most exposed to injury the outer is the thickest of the orbital walls and is especially strong at the orbital margin Behind this is a relatively weaker part then comes a thicker portion and the most posterior portion i e that in relation to the middle cranial fossa is thinner again (Fig 3) The most posterior is in fact the feeblest portion Here on either side of the spheno malar suture it is only 1 mm thick and its lamellar structure makes it transparent In 30 per cent of cases according to Nippert[1] there exist in this area supplementary fissures which represent the extensive primitive communication between the orbit and the temporal fossa

Relations—The outer wall separates the orbit *anteriorly* from the temporal fossa containing the temporal muscle posteriorly from the middle cranial fossa and the temporal lobe of the brain (Figs 3 and 146)

Inside the orbit the lateral rectus muscle is in contact with this wall all the way Above it are the lacrimal nerve and artery

The spina recti lateralis and the *orbital tubercle* with their attachments have already been described as has the zygomatic canal and its contents

The lacrimal gland reaches down on to the outer wall and the *lacrimal nerve* sends an anastomotic branch to join the zygomatic (Fig 147)

The following **fissures** and **canals** lie between the various orbital walls

The superior orbital (sphenoidal) fissure
The inferior orbital (spheno maxillary) fissure
The anterior and posterior ethmoidal canals

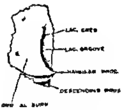

FIG 8—RIGHT LACRIMAL BONE (OUTER VIEW)
From Quain's Anatomy

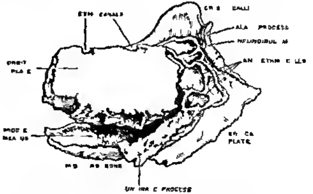

FIG 9—THE ETHMOID BONE (FROM THE RIGHT SIDE)
(From Quain's Anatomy)

The superior orbital (sphenoidal) fissure lies between the roof and lateral wall of the orbit It is the gap between the small and great wings of the sphenoid and is closed laterally by the frontal

[1] Nippert O *Zur Morphologie und Genese der Fossa temporalis* (*Z f Morph* 1931 29 pp 1 8)

It is wider at the medial end where it lies below the optic foramen and is often described as comma shaped Sometimes there is gradual reduction in size towards the lateral extremity but usually it is composed of two limbs a narrow *outer* portion and a wider *medial* part At the junction of the two limbs is the *Spina recti lateralis* (Fig 1)

The superior orbital fissure is some 22 mm long and is the largest communication between the orbit and the middle cranial fossa Its tip is 30 to 40 mm from the fronto malar suture Its medial end is separated from the optic foramen by the posterior root of the small wing of the sphenoid on which is found the infra optic tubercle This lies below and lateral to the optic foramen on the middle of the vertical part of the inner border of the wide part of the superior orbital fissure (Fig 1) The structures that pass through its wide medial

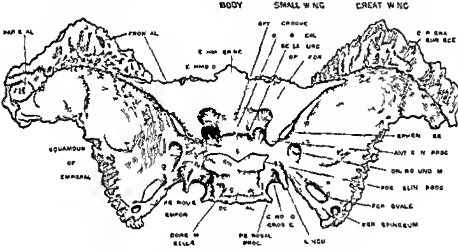

Fig 10—The Sphenoid Bone (from above)
(From Quain's "Anatomy")

portion are related to the annulus of Zinn or to the two heads of the Lateral rectus (Fig 133)

One or more fronto sphenoidal foramina may be present in the fronto sphenoidal suture and transmit an anastomosis between the middle meningeal and the lacrimal arteries

According to Hovelacque *the outer limb is closed by dura mater and nothing passes through it* This is not the usual teaching but it is borne out by my own dissections (see Figs 131 and 132) Passing above the annulus are the fourth frontal and lacrimal nerves the superior ophthalmic vein and the recurrent lacrimal artery

Passing within the annulus or between the two heads of the Lateral rectus are the superior division of the 3rd nerve the naso ciliary and sympathetic root of the ciliary ganglion the inferior division of the 3rd then the 6th (and then sometimes the ophthalmic vein or veins)—in that order from above downwards The

6th nerve is actually passing from below the inferior division of the 3rd to lie lateral and between the two divisions (Fig 133)

As a rule nothing passes below the annulus rarely the inferior ophthalmic vein

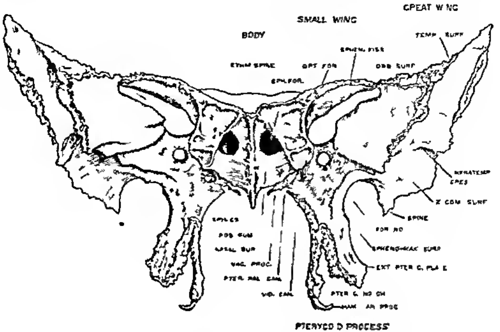

Fig 11 —The Sphenoid Bone (from in front)

(From Quain's "Anatomy")

The inferior orbital (spheno-maxillary) fissure lies between the lateral wall and floor of the orbit Through it the orbit communicates with the pterygo palatine (spheno maxillary) and infra temporal (or zygomatic) fossæ It commences below and lateral to the optic foramen[1] close to the medial end of the superior orbital fissure It runs forwards and outwards for some 20 mm its anterior extremity reaching to about 2 cm from the inferior orbital margin (Figs 1 and 3)

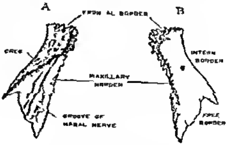

Fig 12 —The Right Nasal Bone (A inner view B outer view)

(From Quain's "Anatomy")

The inferior orbital fissure is bounded anteriorly by the maxilla and the orbital process of the palate bone posteriorly by the whole of the lower margin of the orbital surface of the great wing of the sphenoid In the majority of cases it is closed anteriorly by the zygomatic (malar) bone

The fissure is narrower at its centre than at its two extremities, the anterior end sometimes being markedly expanded

[1] The two fissures are however not continuous, as sometimes stated

The width of the inferior orbital fissure depends on the development of the maxillary antrum and thus is relatively wide in the fœtus and infant

The outer border is sharp and may have grooves above and below it it is higher than the inner border anteriorly but lower posteriorly It is closed in the living by periorbita and the muscle of Muller

The inferior orbital fissure is in close relation posteriorly with the openings of the foramen rotundum and the spheno palatine foramen (Figs 1 and 2)

The inferior orbital fissure transmits the second division of the 5th nerve the zygomatic nerve, branches to the orbital periosteum from the spheno palatine ganglion and a communication between the inferior ophthalmic vein and the pterygoid plexus (Figs 146 and 181)

The ethmoidal foramina lie between the roof and medial wall of the orbit either in the fronto ethmoidal suture *or actually in the frontal bone* They are the openings of canals which are formed in greater part by the frontal but are completed by the ethmoid (Figs 1 2 and 9)

The anterior ethmoidal canal looks backwards as well as outwards Its posterior border is ill defined and continuous with a groove on the lamina papyracea of the ethmoid It opens in the anterior cranial *fossa* at the side of the cribriform plate of the ethmoid and transmits the nasal nerve and artery

The posterior ethmoidal canal opens into the anterior cranial *fossa* and transmits the posterior ethmoidal artery and (sometimes) the small spheno ethmoidal nerve of Luschka (Fig 145) Supplementary foramina are common

The optic foramen, or rather the optic canal leads from the middle cranial fossa to the apex of the orbit and it is formed by the two roots of the lesser wing of the sphenoid It is directed forwards outwards and somewhat downwards its axis making an angle of about 36° with the median sagittal plane If produced forwards the axis passes approximately through the middle of the infero external quadrant of the orbital opening Hence it is neither in the axis of the orbit nor of its outer wall (Winckler) If produced backwards it would meet its fellow at the dorsum sellæ of the sphenoid The canal is funnel shaped the mouth of the funnel being the anterior opening This is oval in shape with the greatest diameter vertical The cranial opening on the other hand is flattened from above down while in its middle portion the canal is circular on section With regard to the intracranial opening the upper and lower borders are sharp the inner and outer rounded The inter optic groove is thus continuous with the inner wall without line of demarcation (Fig 10)

The outer border of the orbital opening is more or less well defined It is formed by the anterior border of the posterior root of the small wing of the sphenoid The inner border is less well defined

The distance between the intracranial openings of the two canals is 25 mm The distance between the orbital openings is 30 mm

The roof of the canal reaches farther forwards than the floor while posteriorly

the floor projects beyond the roof. This gap in the roof is filled in by a fold of dura mater with a free posterior edge (the falciform fold) (Fig 139).

The optic canal is closely related medially to the sphenoidal air sinus, sometimes to a posterior ethmoidal air cell. According to Fazakas[1] the longer the optic canal, the thinner its medial wall and the more likely it is to enter into relation with a posterior ethmoidal air cell. Often only a very thin plate of bone separates the optic canal from these. At times the canal makes a ridge inside the sinus. Not infrequently the sinus or a posterior ethmoidal air cell may invade the small wing to a greater or smaller degree, and they have been known to surround the canal completely.

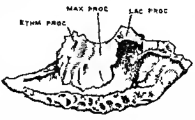

FIG 13.—THE RIGHT INFERIOR TURBINATE BONE (OUTER VIEW)
(From Quain's Anatomy.)

Above the canal is the posterior part of the orbital segment of the first frontal convolution.

The optic canal is separated from the medial end of the superior orbital fissure by a bar of bone, on which there is a tubercle or roughness for the tendon of Zinn (the infra-optic tubercle) (Fig 1).

The optic canal transmits the optic nerve and its coverings of dura, arachnoid, and pia, which are all firmly adherent to its roof (see p 231), the ophthalmic artery, which lies here below then lateral to the nerve and embedded in its dural sheath, and a few twigs from the sympathetic which accompany the artery. Separating artery and nerve is a layer of fibrous tissue which may (rarely) be ossified.

The measurements of the optic canal are as follows (Winckler):

The orbital opening is 6 to 6.5 mm by 4.5 to 5 mm.

The cranial opening is 5 to 6 mm by 4 to 5 mm.

In the middle portion it is 5 by 5 mm.

The canal is further narrowed by the periosteum.

The lateral wall is 5 to 7 mm long, which is the width of the posterior root of the small wing of the sphenoid.

The roof, 10 to 12 mm in length, varies with the development of the small wing of the sphenoid between the anterior clinoid process and the body of the sphenoid.

The upper and inner walls are longer than the others. The longer the optic canal, the narrower it is, and vice versa (Fazakas).

The orbital margin has the form of a quadrilateral with rounded corners.[2] Each side measures some 40 mm, but usually the width is greater than the

[1] Fazakas, S. Die Topographie der Nebenhöhlen (Centralbl f. d. O., 1933, 28, p 494).

[2] As a common variation of this, the orbital margin may have the form of a spiral, the inferior orbital margin being continuous with the anterior lacrimal crest, while the superior is continued down by a roughened line into the posterior lacrimal crest. The lacrimal fossa then lies in the orbital margin (Poirier).

height, the relation between the two is given by the *orbital index*,[1] which varies in the different races of mankind. The opening is directed forwards and slightly laterally, and is tilted so that the upper and lower margins slope gently downwards from the medial to the lateral side.

The orbital margin is made up of three bones, the frontal, zygomatic, and maxilla.

The superior orbital margin is formed entirely of the frontal bone, i.e. by its orbital arch and the lateral and medial angular processes.

It is generally concave downwards, convex forwards, sharp in its outer two thirds, and rounded in the inner third. At the junction of the two portions, some 25 mm. from the midline and situated at the highest part of the arch, is the *supraorbital notch*, whose outer border is usually sharper than the inner. Not infrequently it is converted into a foramen by the ossification of the ligament which closes it below. The posterior opening then is 3 to 6 mm. from the orbital margin. It transmits the supraorbital nerve and vessels.

Sometimes medial to this a second notch (of Arnold) or foramen is found. This transmits the medial branches of the supraorbital nerves and vessels where these have divided inside the orbit.

Supraorbital grooves leading from these notches or foramina are sometimes seen.

A groove may also be present some 10 mm. medial to the supraorbital notch for the supra-trochlear nerve and frontal artery.

A supraciliary canal (Ward) is found in about half the cases (Fig. 1). It is a small opening near the supraorbital notch, and transmits a nutrient artery and the nerve of Kobelt to the frontal air sinus.

The lateral orbital margin, being the most exposed to injury, is the strongest portion of the orbital outlet. It is formed by the lateral angular process of the frontal and by the zygomatic bone. If looked at from the side it appears to be concave forwards and not to reach as far forward as the medial margin.

In the spheno-zygomatic suture there are not infrequently ossicles resembling the Wormian bones of the cranium.

Another suture occurs in 21.1 per cent. of Japanese skulls, in which the zygomatic bone may be in two parts (*Os Japonicum*).

[1] The orbital index (of Broca)—

$$= \frac{\text{Height of Orbit} \times 100}{\text{Width of Orbit}}$$

Taking the orbital index as the standard, three classes of orbit are recognised.

1. *Megaseme (large)*.—The orbital index is 89 or over. This type is characteristic of the yellow races except the Esquimaux. The orbital opening is round.

2. *Mesoseme (intermediate)*.—Orbital index between 89 and 83. This type is found in the white races (European 87, English 88.4, according to Flower).

3. *Microseme (small)*.—Orbital index 83 or less. This type is characteristic of the black races. The orbital opening is rectangular.

The inferior orbital margin is raised slightly above the floor of the orbit It is formed by the malar and the maxilla, usually in equal portions

The zygomatic portion forms a long thin spur (the marginal process) which lies on the maxilla (Figs 1 and 4)

The suture between the two, which is not infrequently marked by a tubercle, can be felt lying usually about half way along the margin just above the infraorbital foramen (Fig 1)

Sometimes, however, the zygomatic (malar) may reach the anterior lacrimal crest, thus excluding the maxilla, or may take only a very small part itself in the formation of this margin

The medial margin is formed by the anterior lacrimal crest on the frontal process of the superior maxilla and the internal angular process of the frontal Below it is sharp, above it runs smoothly into the nose At its junction with the inferior margin is the lacrimal tubercle (Fig 1)

Age and Sex Changes

The orbital margin is rounded and well ossified at birth As Fisher points out "The eyeball is therefore well protected from stress and injury during parturition When we recollect the relatively large size and the advanced stage of development of the eye at birth, it is clearly specially desirable that such protection should be afforded, that it is efficacious, the rarity of birth injuries of the globe in cases of unassisted labour can testify"

The form of the orbit on frontal section behind the orbital margin is that of a quadrilateral with rounded corners In the newborn it has the form of an ellipse higher on the lateral than on the medial side

The infantile orbits look much more laterally than the adult, i e their axes, or the lines drawn from the middle of the orbital opening to the optic foramen, make an angle of 115°, and, if produced backwards, meet in the middle of the nasal septum In the adult the axes make an angle of 40°—45° with each other and, if produced backwards, meet at the upper part of clivus of the sphenoid These axes, too, lie in the horizontal plane in the infant, whereas in the adult they slope downwards from 15° to 20°

The orbital fissures are relatively large in the child owing to the narrowness of the orbital surface of the great wing of the sphenoid

The orbital index is high in the child, the vertical diameter of the orbital opening being practically the same as the horizontal The size of the orbits is relatively great, thus they do not grow much after seven years

The interorbital distance is small This is of some practical importance *Children are not infrequently brought to the ophthalmic surgeon because they are thought to squint when the strabismus is apparent only This appearance is due to the narrow interorbital distance, which makes the eyes look too close together. With the growth of the frontal and ethmoidal air cells the interorbital distance increases, and so causes the "squint" to disappear*

Senile Changes —Here the changes are those due to absorption of the bony walls Thus in the skulls of old people frequently holes are found in the *roof* of the orbit In such cases the periorbita is in direct contact with the dura mater

The medial wall although normally very thin rarely shows senile holes in its ethmoidal portion Parts of the lacrimal bone are however so commonly absorbed that it is rare to find it complete in the adult skull

The lateral wall not uncommonly shows holes or such marked thinning that it becomes very fragile in these places

As regards the *floor* senile changes very rarely produce holes apart from those in the roof or floor of the infraorbital canal

In old people too the orbital fissures especially the inferior become wider owing to absorption of their margins

In longheaded (dolichocephalic) skulls the orbits tend to look more laterally than in the shortheaded (brachycephalic) (Mannhardt *Archiv fur Ophth* 17 Bd II Abt 1871)

Mensuration —There is a great difference between the measurements given by different authorities The following is a useful average

Depth of orbit	40 mm
Height of orbital opening	[illegible] mm
Width of orbital opening	40 mm
Interorbital distance	5 mm
Volume	30 c c
Volume of orbit Vol of eye 4 1 (Ov[illegible])	

Sex Differences —Up to puberty there is little difference between the orbits and in fact the skulls of male and female

After this the male skull takes on its secondary sexual characters seen especially in the formation of the lower jaw and in the forehead region

The female remains more infantile in form The orbits tend to be rounder and the upper margin sharper than in the male The glabella and superciliary ridges are less marked or almost absent The forehead is more vertical and the frontal eminences more marked The contours of the region are rounder and the bones smoother The lateral angular process is more slender and pointed

The female orbit is more elongated and relatively larger than the male (Merkel)

The Periorbita (Fig 143)

The periorbita or orbital periosteum lines the bones of the orbit Generally it adheres but loosely to the bones which it covers so that for the most part it may be lifted from them by blood or pus or during the course of certain operations

At various points however it is firmly fixed

(1) At the orbital margin where it is thickened to form the Arcus marginale and becomes continuous with the periosteum covering the bones of the face

(2) At the sutures

(3) At the various fissures and foramina and
(4) At the lacrimal fossa

Through the superior orbital fissure the optic foramen and ethmoidal canals (Fig 143) it becomes continuous with the dura mater

In the superior orbital fissure it becomes a dense membrane which just allows sufficient room for the various structures to pass through

In the optic foramen the upper part of the nerve and its sheaths are closely adherent to the periosteum of the roof of the canal (see p 231)

Through the inferior orbital fissure it is continuous with the periosteum covering the bones of the infratemporal or zygomatic fossae through the temporal canal with that of the temporal fossa and via the zygomatic canal with that on the front of the malar bone

At the posterior lacrimal crest it splits to enclose the lacrimal fossa being separated from the sac by some loose areolar tissue and then passes down the duct to become continuous with the periosteum of the inferior meatus

These facts can be made out and should be remembered in doing an exenteration of the orbit Having divided the periosteum at the orbital margin one finds little difficulty in removing the periosteal cone except at the above places where bands of varying strength have to be divided

The periorbita is liable to become ossified especially where it roofs over the inferior orbital canal and where it is attached to the posterior lacrimal crest

The Muscle of Muller (*Musculus orbitalis*)—In the region of the inferior orbital (spheno maxillary) fissure some plain muscle fibres are found with the periorbita This is the muscle of Muller It is more extensive than one would imagine It not only spans the spheno maxillary fissure but extends backwards deep to the tendon of Zinn to the front of the cavernous sinus while anteriorly it gradually gets lost in the periorbita It has a width of 12 mm Its action in the human is very doubtful In certain mammals where there is no long outer wall to separate the orbit from the temporal fossa the muscle of Muller is large and takes the place of this wall (see also p 346)

Relations—Above is orbital fat in which are the inferior ophthalmic vein and its tributaries The inferior surface lies on the fatty tissue of the pterygo maxillary fossa in which are found the infraorbital nerve the spheno palatine ganglion with the arteries and veins surrounding it Through the muscle pass anastomotic branches between the ophthalmic and veins of the pterygoid plexus

Nerve supply—Branch from the spheno palatine ganglion

Function—The muscle is held by some to be the cause of the proptosis in exophthalmic goitre either directly or indirectly through pressure on the veins which pass through it But while the muscle acts as a protruder in some of the lower animals it does not act in this way in man in whom it is vestigial. The free venous anastomosis moreover negatives any effect which a compression of the veins might have had

CERTAIN POINTS OF IMPORTANCE IN THE NEIGHBOURHOOD OF THE ORBITAL MARGIN

The Superciliary Ridges are elevations above the orbital margins which meet in the mid line in the *glabella* which forms the prominence above the nose The prominence of the ridges and of the glabella has nothing to do with the size of the frontal sinuses They are larger in the male than in the female and absent in the infant

The Frontal Eminences are rounded elevations on the vertical plate of the frontal bone some 2 in above the orbit they are more prominent in the female and even more so in the infant

The Infraorbital Foramen lies 4 5 mm below the tubercle on the lower orbital margin which marks the suture between the malar and the maxilla It is usually oval and looks downwards as well as forwards Its upper margin is sharp and crescentic while the lower border is ill defined The foramen may be double—indeed up to five have been described

The supraorbital notch, the infraorbital foramen and the mental foramen are on the same vertical line which passes between the two bicuspid teeth

The Temporal Crest runs from the external angular process upwards and backwards to become continuous with the temporal lines on the parietal bones

The Sutura Notha (Fig 1) is a groove on the frontal process of the superior maxilla, and runs parallel with the anterior lacrimal crest It lodges a branch of the infraorbital artery

SURFACE ANATOMY

The Upper Orbital Margin forms a well marked prominence, more so in the outer sharp portion than in the inner more rounded part Its form can be made out easily by touch

It should be noted carefully that the eyebrow corresponds in position only in part to the upper orbital margin

The head of the eyebrow lies for the most part *under* the inner part of the margin to palpate which the finger must press *upwards*

The body lies *along* the margin while the tail runs well above the outer part of the margin which can be felt and usually seen below it

The external angular process often forms a marked prominence under the skin

The Supraorbital Notch can be felt at the junction of the outer two thirds with the middle third and not infrequently the supraorbital nerve can be rolled under the finger

The Outer Orbital Margin is only visible down to the level of the external canthus, but can easily be felt in its whole extent

The Lower Orbital Margin, as opposed to the upper, forms no prominence, since the skin of the lower lid passes without sudden change of plane into that

of the cheek. *Just beyond it, especially in the old, lie the naso-jugal and malar furrows.*

It is easily palpable as a sharp ridge beyond which the finger can pass into the orbit. On the lower and outer side the little finger can pass between the eye and the orbital margin for about ½ in. (1·25 cm.).

The Lacrimal Tubercle can be felt in the sharp anterior lacrimal crest, as can the **tubercle** at the middle of the lower margin which marks the suture between the malar and maxilla.

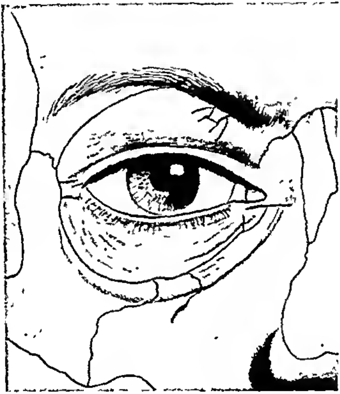

FIG 14.—THE SURFACE ANATOMY OF THE ORBITAL OPENING.

The pulley of the superior oblique is easily felt with the tip of the thumb, just within the supero-medial angle of the orbital margin

The Lateral Orbital Tubercle (Whitnall's) can be felt just within the lateral orbital margin at its middle by passing the finger into the orbit and rubbing it up and down against the margin.

The Infraorbital Foramen, or rather its sharp crescentic upper margin, can not infrequently be made out 4–5 mm. below the tubercle on the lower orbital margin which marks the malar maxillary suture.

The Zygomatic (Malar) Tubercle can be felt below and behind the external

angular process and between the two is a V shaped interval at the bottom of which is the fronto malar suture

The Anterior Lacrimal Crest is easily defined Behind it the finger passes into the lacrimal fossa and behind this again the posterior lacrimal crest can be felt

It should be noted carefully that the finger in the lacrimal fossa lies below the inner angle of the eye and not under the ridge made by the medial palpebral ligament

The Temporal Crest can be felt arching backwards from the external angular process.

The Nasal Bone, sitting on the frontal process of the superior maxilla can be seen and palpated down to its lower end where it joins the mobile cartilage of the nose

The Accessory Sinuses of the Nose

The Maxillary Antrum —The maxillary antrum (antrum of Highmore) is a pyramidal cavity situated in the superior maxilla (Figs 2 15)

Its base forms part of the lateral wall of the nose its apex lies under the malar bone In the disarticulated skull the base presents a large opening which is however partly closed in the recent state by the uncinate process of the ethmoid above the inferior turbinate below the palate behind and the lacrimal in front (Fig 2) The mucous membrane covers this in still further so that finally there is only one small opening (sometimes two) situated near the roof of the antrum and therefore bad for drainage and opening into the middle meatus of the nose in the hiatus semilunaris (Fig 16) The naso lacrimal duct forms a ridge in the anterior part of this wall (Fig 15)

The antero lateral wall looks on to the face and may be reached by everting the upper lip In it are the canals containing the anterior and middle superior alveolar (dental) nerves (Fig 152)

The posterior wall faces the infratemporal or zygomatic fossa of which it forms the anterior wall In it are the canals for the posterior superior alveolar (dental) nerves

The roof of the antrum is formed by the orbital plate of the maxilla which constitutes the floor of the orbit In it is the infraorbital canal containing the infraorbital nerve and vessels

The floor is formed by the alveolar margin and is about ½ in (1 25 cm) below the nose In it are seen elevations produced by the roots of some of the upper teeth the most usual being the 1st and 2nd molars but all the true maxillary teeth i e from the canine to the wisdom may be in relation to it Sometimes the fangs actually project into the sinus

The Frontal Sinuses —The frontal sinuses are cavities of variable extent situated anteriorly between the two plates of the frontal bone (Figs 2 143 145) They are separated by a septum which is often deviated to one or other side

In the peripheral parts of the sinus there are also small partitions forming loculi In some cases a frontal sinus may extend outwards to the external angular

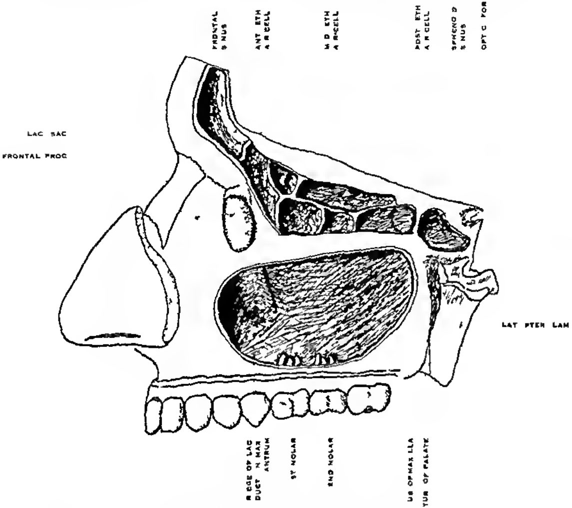

Fig 15—The Accessory Sinuses of the Nose

process at others especially if the septum is much to one side, it may be reduced to a mere slit

On an average (Logan Turner) the height is $1\frac{1}{4}$ in (3 cm), the breadth 1 in (2 5 cm) and depth $\frac{3}{4}$ in (2 cm)

The posterior wall of the sinus is thin contains no diploe, and separates it from the meninges and frontal convolutions

The anterior wall looks on to the forehead It contains diploe hence osteo myelitis spreads more readily in this than in the posterior wall

The floor of the frontal sinus separates it from the orbit and nose

Behind and below the ethmoidal air cells are only separated from the sinus by a thin plate of bone Not infrequently a *fronto ethmoidal air cell* forms a prominence in the floor of the sinus (Fig 2)

The frontal sinus opens into the nose by the infundibulum This narrow canal passes between the anterior ethmoidal air cells and opens into the hiatus semilunaris in the middle meatus, close to the openings of the anterior ethmoidal air-cells and the maxillary antrum (Fig 16)

Hence infection in one sinus can and does easily spread to the others

The Ethmoidal Air-cells —The ethmoidal air cells are situated for the most part in the lateral mass of the ethmoid but are completed by the frontal palate, sphenoid, superior maxilla, and lacrimal

Above them are the meninges and frontal convolutions in the anterior cranial fossa

In front is the frontal sinus, behind the sphenoidal sinus

Below is the nose, laterally the orbit and lacrimal fossa (See Figs 3 and 143)

The air cells are separated from these structures by very thin plates of bone which are not good barriers to the spread of infection Thus the lamina papyracea, as its name implies, is not much thicker than paper hence the reason why ethmoiditis is the commonest cause of orbital cellulitis

The ethmoidal air cells are divided arbitrarily into anterior middle and posterior

The anterior and middle open into the middle meatus of the nose the anterior in the hiatus semilunaris the middle on the bulla ethmoidalis (Fig 16)

The posterior form a medial relation to the optic canal and open into the superior meatus

The Sphenoidal Air Sinus —The sphenoidal sinus lies in the body of the sphenoid bone (Fig 182)

There is a vertical median septum often deviated to one or other side of the midline A variable amount of a transverse septum is also usually present and runs most often from above downwards and forwards It is known as the "carotid buttress" (Cushing) because it is used as a landmark for protecting the internal carotid artery when approaching the pituitary body by the nasal route According to Cope[1] it can be seen in a fourth of the X rays of the region

Above the sphenoidal sinus are the pituitary body and the optic nerve which often makes a ridge inside the sinus It is this close relation which causes the optic nerve to be involved at times in sinusitis giving rise to a sudden loss of vision (retro bulbar neuritis)

Below is the nose

In front are the ethmoidal air cells, the posterior of which often bulges into the sinus

Laterally are the cavernous sinuses, containing the internal carotid artery and the 6th nerve

The sphenoidal sinus opens into the highest meatus, or spheno ethmoidal recess

[1] *Brit Journ of Surg* 1917

When the sphenoidal sinus is very large it may send a prolongation between the foramen rotundum and the foramen ovale. Such an extension of the sinus may explain certain cases of involvement of the nerves in sinus disease.

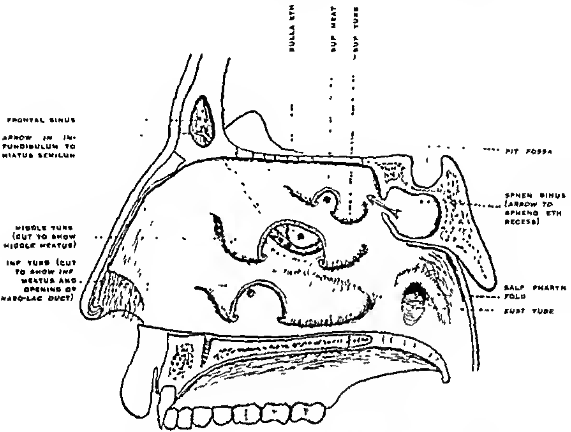

Fig. 16.—The Lateral Wall of the Nose to show the Openings of the Accessory Sinuses and Naso-lacrimal Duct.

Development

The accessory sinuses of the nose all arise as out-buddings from the nasal mucosa.

The bud which is to form the frontal sinus passes up through the ethmoid bone, and at birth is just present in the frontal bone. The stalk remains as the fronto-nasal duct. At 7 years it is about the size of a pea. Then it starts growing rapidly, but does not reach its full size till about 25 years.

Similarly, the ethmoidal air-cells are just present at birth as small depressions, and grow rapidly after 7 years.

At 2 years the sphenoid bone is still spongy, the sphenoidal sinus being represented by a slight depression at its future opening. It really only starts growing at 8 years.

The maxillary antrum is a groove in the lateral nasal wall at birth At 1 year it has just reached the infraorbital canal It grows rapidly with the second dentition, so that at 12 years it is nearly like the adult, whose form, however, it does not acquire till 18 years

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CHAPTER II

THE EYEBALL

ALTHOUGH we speak of the globe of the eye it is not a true sphere but consists of the segments of two somewhat modified spheres placed one in front of the other The anterior of these two segments is the smaller more curved than the posterior and called the *cornea*

It is for this reason that the antero posterior diameter of the globe is greatest (24 mm) Also the eyeball is slightly flattened from above down hence the vertical diameter (23 mm) is slightly less than the horizontal (23 5 mm)

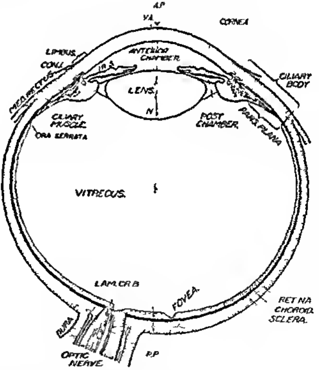


FIG 1 —HORIZONTAL SECTION OF THE EYE

P P = posterior pole
A P anterior pole
V A visual axis

(*Modified from Salzmann*)

So constituted the eyeball is placed in the anterior part of the orbit nearer the roof than the floor and slightly closer to the outer than the inner wall

As regards the depth that it normally occupies in its socket a straight edge placed against the superior and inferior orbital margins will just touch or just miss the front of the cornea

But a line joining the inner and outer margins will have nearly one third of the globe in front of it

The eyeball is in fact least protected on the outer side and it is therefore from this side that the surgeon finds his easiest approach

For this reason too rupture of the globe takes place most frequently up and in from blows which come from the lower and outer side

The globe of the eye consists of three concentric coverings or tunics enclosing the various transparent media through which the light must pass before reaching the sensitive retina

1 The outermost coat is fibrous protective in function and made up of a

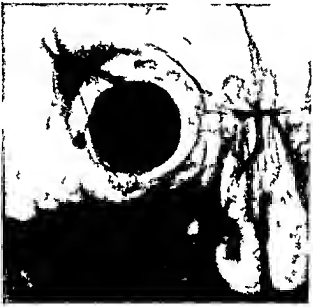


FIG 18.—TO SHOW THE POSITION OF THE EYE IN THE ORBIT

The eye was injected with a saturated solution of lead nitrate before the X ray was taken The actual injection fluid was kindly suggested to him by Professor H A Harris

posterior five-sixths which is white and opaque and called the *sclera* and an anterior part transparent the *cornea*

2 The middle coat is mainly vascular and nutritive in its function It is made up from behind forwards of choroid ciliary body and iris

3 The innermost tunic is the retina consisting essentially of nerve elements and forming the true receptive portion for visual impressions

THE CORNEA

The cornea is transparent and resembles a little watch-glass Its curvature is somewhat greater than the rest of the globe and so a slight furrow (the sulcus scleræ) separates it from the sclera

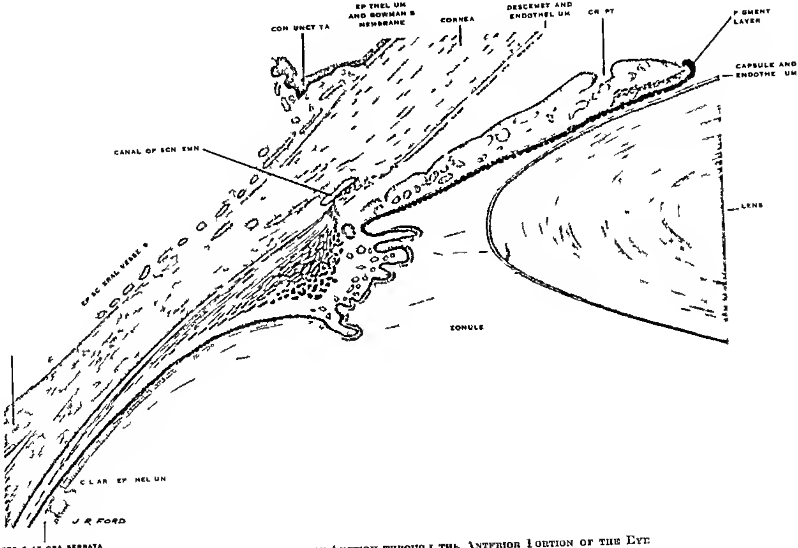
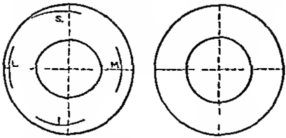


FIG 10 —ANTERO-POSTERIOR SECTION THROUGH THE ANTERIOR PORTION OF THE EYE

This furrow is best demonstrated in the living by making the image reflected from a mirror pass from the cornea to sclera. The image is first narrowed horizontally (Tscherning), then may divide into two.



(From in front.) (From behind.)

FIG. 20.—TO SHOW THE CORNEA—OVAL FROM IN FRONT—CIRCULAR FROM BEHIND.

Just as a watch glass fits into its groove, so does the cornea fit into a groove in the sclera. The simile must not lead one to believe, however, that the cornea can be easily separated from the sclera, for the two are structurally continuous, and histologically it is almost impossible to tell where one ends and the other begins. Looked at from in front, the cornea is elliptical, being 12 mm. in the horizontal meridian and 11 mm. in the vertical.

From behind, the circumference of the cornea appears circular. This difference is due to the fact that the sclera and conjunctiva overlap the cornea anteriorly more above and below than laterally.

Ideally the cornea forms part of the circumference of a sphere, but very often it is curved[1] more in one meridian than another, *giving rise to the condition of astigmatism*.

The radius of curvature of the anterior surface is 7.84 mm. (Steiger), that of the posterior

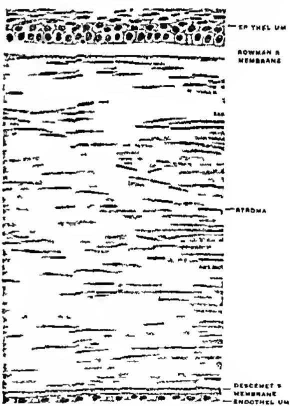


FIG. 21.—TRANSVERSE SECTION OF CORNEA.

[1] Usually it is more curved in the vertical than in the horizontal meridian, i.e. astigmatism with the rule.

7 mm (Merkel and Kallius) These radii only hold good for the central third, or optical zone, the peripheral portions being more flattened *Hence a higher convex glass is often necessary when looking at the periphery of the fundus with the ophthalmoscope*

The cornea is slightly thicker at the periphery (1 mm) than at the centre, where it is 0 8 mm [1]

Contrary to popular opinion, most of the refraction of the eye takes place, not in the lens, but at the surface of the cornea

Structure.—On microscopic section the following five layers, taking them from before backwards, can be made out in the cornea

1—*Layer of Stratified Epithelium.*—This may be regarded as the continuation of the conjunctiva forwards It is some 50–100μ in thickness and consists of five layers of cells (Virchow) The deepest of these, the *Basal* cells, are columnar, with rounded heads and flat bases which often present processes that spread out on Bowman's membrane Each has a slightly oval nucleus whose long axis is that of the cell

The next layer (the *Wing* [or umbrella] cells) consists of polyhedral cells whose rounded heads are directed anteriorly and whose concave bases fit over the heads of the basal cells and send processes, the wings, between them Each contains an oval nucleus whose long axis is parallel with the surface of the cornea

The next two or three layers are also polyhedral, and the most superficial are flattened but do not lose their nuclei, *nor do they normally show keratinisation*

As in the epidermis, the various cells are united by cell bridges forming prickle-cells The spaces between the cells form a lymph space which can be injected, and *which may be greatly distended pathologically, for instance in glaucoma* These spaces are best seen between the basal cells, and gradually disappear in the more superficial ones

A few leucocytes (wandering cells) may be found normally in the spaces between the basal cells just in front of Bowman's membrane (Fig 21) Pathologically they may increase greatly in number

2 *Bowman's Membrane* or the anterior "elastic" lamina, is a thin structureless sheet placed between the epithelial cells and the substantia propria It is separated from the epithelium by a sharply defined border, *and under pathological conditions as well as after death the epithelium separates readily from Bowman's membrane* Posteriorly the line of demarcation from the stroma is ill defined In fact, it may be regarded as a modified portion of the stroma Peripherally it ends abruptly in a rounded border (Figs 19 and 22)

Bowman's membrane is not a true elastic membrane nor does it regenerate when once it has been destroyed It, however, shows a good deal of resistance to injury or infection

3 *The Substantia propria* consists of transparent almost structureless lamellæ of fibrous tissue placed one on the other and firmly united together

[1] According to Koby (*Rev gen d'Opth*, June–July, 1930), using the slit lamp, the thickness of the cornea at the centre is only 0 58 mm

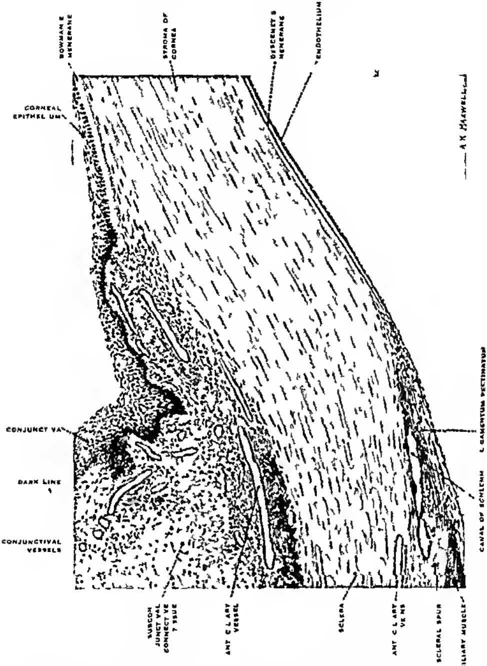


FIG 22.—SECTION AT THE CORNEO SCLERAL JUNCTION

Each lamella consists of minute connective tissue fibrils which are united by a cement substance

While the lamellæ of any particular layer are parallel with each other,

succeeding layers may make angles (up to a right angle) with each other *It is this lamination of the cornea which explains why the beginner in making a corneal section (for instance in cataract extraction) so often finds the knife splitting the cornea instead of passing through it*

Between the lamellæ are found

(a) Fixed cells.

(b) Wandering cells

Fixed cells are connective tissue cells, called here corneal corpuscles, which resemble the corpuscles of the Haversian system of bone Each consists of a

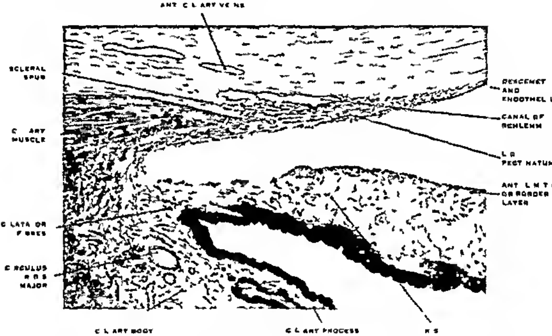


FIG 23 —SECTION OF THE ANGLE OF THE ANTERIOR CHAMBER (Same slide as Fig 22)

flattened cell with a large flattened nucleus and having branching processes which communicate with those of neighbouring corpuscles

Wandering white cells may also be seen They escape from the marginal loops of the corneal blood vessels are few in number normally but play an important part in inflammation

4 *Descemet's Membrane* (or posterior elastic membrane) is a strong, structureless, and very resistant membrane Unlike Bowman's membrane it is sharply defined from the corneal stroma It is very resistant to chemical reagents and likewise to pathological processes going on in the cornea When the entire cornea has broken down into pus, we often see the thin Descemet's membrane offering resistance and remaining unimpaired for days (Fuchs)

Descemet's membrane is normally in a state of tension if wounded it

gapes slightly and tends to assume a curve which is the opposite of the normal i e it tends to curl up and roll out (Salzmann) While showing this type of elasticity it does not stain with all elastic stains although it does with some In fact it agrees very much in its staining reactions with those of the capsule of the lens

Unlike Bowman s membrane, which never regenerates Descemet s membrane can be re formed.

Descemet's membrane often tapers at its edge but although it appears to end here it can be traced into a *portion* of the Ligamentum pectinatum iridis (see below)

Thus this ligament is not formed of a fibrillation of Descemet as often stated, for it contains other structures besides it (p 39)

At the periphery of the cornea the posterior surface of the membrane presents rounded wart like elevations the Hassal Henle bodies which tend to increase in old age (see p 166)

5 *The Endothelium* is the most posterior layer of the cornea, and consists of a single layer of flattened epithelial like cells continuous round the angle of the anterior chamber with those on the front of the iris The cells at the back of the cornea with their nuclei can be seen by means of the slit lamp in the living eye—the only place in the body where this is possible (see p 165)

Embryologically the cornea is the continuation forwards of three structures

(a) The epithelium and Bowman s membrane of the conjunctiva

(b) The substantia propria of the sclera

(c) Descemet s membrane and the posterior endothelium of the uveal tract

Pathologically, too this is of importance, for the epithelium is liable to be affected in diseases of the conjunctiva, the stroma in diseases of the sclera and Descemet and the endothelium in diseases of the uveal tract

THE LIMBUS

As we approach the limbus that is the 1 mm transition zone between the cornea on the one hand and the conjunctiva and sclera on the other the epithelium becomes thicker, up to ten or more layers. Its posterior border becomes wavy and may even present a papillary appearance. The cells of the basal layer become smaller poorer in protoplasm and the nuclei small and more densely staining This causes the basal layer to appear under the low power of the microscope as a *dark line* which is characteristic of the limbus and conjunctiva (Fig 22)

At the limbus the stroma of the cornea loses the regular arrangement of its lamellæ and becomes more like ordinary connective tissue This change is first seen in the superficial layers then in the deeper

Here too, we find the marginal vessels and sparse elastic fibres, which increase as we pass towards the sclera The marginal vessels (superficial marginal plexus) lie for the most part superficially They occupy a triangular area whose apex lies where Bowman s membrane ends, and whose base is formed by episcleral tissue and sclera

The Vessels and Nerves of the Cornea

The cornea is avascular, except for small loops derived from the anterior ciliary vessels, which invade the periphery for 1 mm only. The nourishment is obtained by lymphatic permeation through the spaces between the lamellæ. No actual lymphatic vessels lined by endothelium are found.

Von Recklinghausen's canals and Bowman's tubes are artefacts.

Nerves.—The cornea is supplied by the ophthalmic division of the 5th cranial via the ciliary nerves and those of the surrounding conjunctiva. *The first division of the 5th nerve in fact supplies almost the whole of the eye and its appendages giving warning of injury, for instance of a foreign body, and hence may well be called the sentinel of the eye.* The anterior ciliary nerves enter the sclera from the perichoroidal space a short distance behind the limbus. They anastomose with each other and with the conjunctival nerves, forming pericorneal plexuses at various levels. The nerves pass into the cornea as 60–80 myelinated trunks at its junction with the sclera. After having gone about 2–4 mm., they usually lose their myelin sheaths and divide into two groups—anterior and posterior. The anterior (40–50) pass through the substance of the cornea and then form a plexus under Bowman's membrane. Having traversed this, the fibres anastomose again to form a subepithelial plexus, and lastly actually in amongst the epithelial cells an intraepithelial plexus[1] is found.

The posterior (40 or 50) pass to the posterior part of the cornea. According to Dogiel, the nerves in the stroma at the periphery of the cornea end in small plates with serrated edges. Krause's end bulbs are found beneath the epithelium at the limbus, and in the epithelium of the cornea itself the nerves end in rounded or pear-shaped end bulbs.

The Sclera (from σκληρός = hard)

The sclera forms the posterior opaque five-sixths of the fibrous protective coat of the eye. Its anterior portion is visible and constitutes the "white" of the eye.

In childhood (or pathologically) when the sclera is thin it appears bluish *owing to the uvea showing through.* *In old age it may become yellowish owing* to a deposition of fat. The inner surface of the sclera is brown owing to adherent suprachoroidal pigment and is marked by grooves in which the ciliary nerves and vessels lie.

The sclera is thickest behind (about 1 mm.), and gradually becomes thinner as we trace it forwards. It is very thin at the insertion of the recti muscles (0.3 mm.), but the thickness of tendon and muscle = 0.6 mm. (Fig. 28). At the site of attachment of the optic nerve 3 mm. to the inner side of and just *above* the posterior pole of the eye, the sclera becomes a thin sieve-like mem-

[1] While this is the classical description, it would appear that in man the three plexuses cannot be demonstrated as they can in the lower animals.

brane—the *lamina cribrosa*, through the holes of which the axones of the ganglion cells of the retina pass

The lamina cribrosa forms the weakest spot in the outer fibrous tunic of the eye In glaucoma therefore, it is here that the eye will give, and result in the cupped disc—characteristic of the *chronic* form of the disease when the intra ocular pressure has been raised for some time

Moreover, as the fibres of the optic nerve pass through the lamina cribrosa they lie in canals whose walls are little distensible and hence are easily strangulated by inflammatory swelling

The outer surface of the sclera is received into the capsule of Tenon to which it is connected by fine trabeculæ (see also p 185)

The sclera is pierced by three sets of apertures—posterior middle, and anterior

The Posterior apertures are situated round the optic nerve and through them pass the long and short posterior ciliary vessels and nerves

The Middle apertures 4 mm behind the equator of the eye give exit to the venæ vorticosæ which come from the choroid and some lymphatics

The Anterior apertures are for the anterior ciliary vessels (which come from the muscular branches to the recti), perivascular lymphatics and sometimes nerves which may have ganglia on them (see also p 38)

Structure.—The sclerotic consists of dense bands of fibrous tissue some 10–16 μ in thickness and 100–140 μ in width. The bands are mostly parallel with the surface and cross each other in all directions They may divide dichotomously and then reunite The imbrication of the fibres is so dense, especially in its posterior part that it is almost impossible to separate them by dissection The deeper bands are stronger than those next the episclera The tendons of insertion of the recti muscles run into the sclera as parallel fibres and then spread out in a fan shaped manner to become lost among the meridional fibres of the sclerotic

The tendons of the oblique muscles behave similarly but here they lose themselves among the oblique or equatorial fibres of the sclera

Just as the direction and strength of the bony trabeculæ of the shaft of the femur are determined by the stresses and strains to which it is subject, so the plan of the scleral fibres is determined by the intraocular tension and the pull of the various muscles

The adaptation of the sclerotic to these stresses and strains is effected by the disposition of the fibrous bands, by the wavy course of the connective tissue fibres, and by the great abundance of the elastic fibres (Redslob)

The different parts of the sclerotic have different functions to perform This is recognised by the orientation of the fibres In the posterior portion the external fibres are arranged like the net around a balloon, while the internal fibres spread out fanwise Thus they will give gradually in a case of increased intraocular tension Moreover the wavy fibres become straight due to the tension of the

elastic fibres. When the tension diminishes, the elastic fibres are relaxed and the connective tissue fibres become wavy again. Everything takes place as if the sclerotic were a spring (Redslob).

The anterior portion has a different function. It forms a rigid skeleton for the insertion of the ocular muscles. This rigidity is brought about by the strictly circular direction of the scleral fibres.

With age the connective tissue fibres tend to become sclerosed. This condensation is seen especially around the canals of the venæ vorticosæ.

The sclera is very rich in elastic fibres placed on the surface of the fibrous bands. They are especially abundant at the equator around the optic nerve and at the limbus.

Elastic fibres are not present in the embryo. They only develop after birth and increase up to adult life. In old age they diminish again.

The fixed cells of the scleral tissue resemble those of the cornea, but the nuclei are more irregular, and the syncytium formed by the processes not so closed (Salzmann).

FIG. 24.—TO SHOW THE STRUCTURE OF THE SCLERA AND THE LONG POSTERIOR CILIARY NERVE IN THE SUPRACHOROIDAL SPACE. (ZENKER, MALLORY'S PHOSPHOTUNG HAEM.)

(Author's preparation.)

Pigmented cells of various shapes are met with, especially in the deeper layers near the choroid, and on the vessels and nerves which pass through the sclera. Also at the points where the anterior ciliary vessels enter there is often a collection of pigment, especially in dark people.

These pigment cells have obviously migrated from the uvea, and point the way by which malignant disease of the interior of the eye often makes its way to the outside.

If a section be taken passing through the cornea and sclera, no line of demarcation can be made out, the fibres of one being continuous with those of the other. At their junction, however, we find the canal of Schlemm.[1]

The sclera is almost avascular except for the vessels which pass through it to and from the interior of the eye.

[1] *The corneo-scleral junction is best seen by looking with the naked eye at a freshly enucleated globe which has just been sectioned.*

Posteriorly around the optic nerve we find the circle of Zinn or Haller

The episcleral tissue is the loose connective and elastic tissue which covers the sclera and anteriorly connects the conjunctiva to it. It is for the most part continuous superficially with the loose tissue of Tenon's space, while its deeper layers become more and more dense and gradually give place to sclera proper. It differs both from the loose tissue of Tenon's space and the sclera, both of which are relatively avascular, by containing quite a fair number of vessels.

Behind the insertion of the recti muscles the episcleral tissue is thin and the vessels, two veins to each artery, form a wide meshed net. The arteries here come from the posterior ciliaries.

In front of the attachment of the muscles the episclera is much thicker and much richer in vessels. The meshes of the vascular net too, are much smaller. A capillary net only exists in this anterior zone of the sclera. It is a marked filling of this net which is called "ciliary injection" (Salzmann).

Nerves of the Sclerotic.—The ciliary nerves pierce the sclerotic around the optic nerve. The long ciliary nerves accompany the long posterior ciliary arteries and so reach the ciliary body. At the level of the orbiculus ciliaris the nerves divide into branches. Some go to the ciliary body, some accompanied by vessels penetrate the sclerotic, most commonly at the equator or some 2–4 mm. from the limbus. When they reach the surface the branches anastomose, forming loops around the limbus from the convexity of which branches pass into the cornea.

Nerves also pass from the episcleral tissue inwards into the sclera.

Some scleral nerves have a curious course. They enter the sclerotic and may even reach its outer surface. They then bend round sharply and turn back to the point of entrance. The extremity of the loop sometimes presents a mushroom like thickening. These scleral loops are found most commonly about 1.6 mm. from the limbus. In their intrascleral course the nerves are often accompanied by pigment and appear under the conjunctiva as hyaline elevations surrounded by a ring of pigment which are very sensitive (Redslob).

THE CANAL OF SCHLEMM (SINUS VENOSUS SCLERÆ)

The canal of Schlemm is a space which, placed in the corneo scleral junction, encircles the angle of the anterior chamber. On section it is oval and often double. It may, in fact, be compared to a stream which divides into two or more tributaries and then reunites again (Salzmann).

It is lined by endothelium whose nuclei project inwards, and is separated from the sclera by a variable amount of connective tissue rich in cells.

Behind the canal of Schlemm is the scleral spur (Figs. 19, 21, 22), which also overlaps it somewhat on the inner side. Medial to the canal are the trabeculæ forming the spaces[1] of Fontana.

[1] The so-called spaces of Fontana in the human are not exactly homologous with the spaces described by Fontana in the lower animals. These do occur in the human fœtus up to 6 months but later disappear.

There is no direct communication with these spaces, but solutions pass very easily from the anterior chamber into the canal of Schlemm. Particulate matter, including cells, are held up by the trabecular network.

There is a direct communication with the anterior ciliary veins (*see later*).

Thus the aqueous passes from the anterior chamber into the canal and thence to the anterior ciliary veins.

There is still much dispute as to whether the canal of Schlemm is a venous or lymphatic channel. Many anatomists regard it as a venous channel, though normally no blood corpuscles or only a few are found in it. Moreover, no real valves have been found between it and the anterior ciliary veins.

According to Maggiore, however, the connecting channels between the canal of Schlemm and the ciliary veins are minute, flattened, and have an oblique course. They could therefore act as modified valves, and tend to prevent blood getting into the canal. Normally this valvular action is competent to withstand the venous pressure, and thus the canal usually contains aqueous. Under conditions of congestion the valvular action breaks down and blood passes into the canal. This is borne out by the observations of Troncoso with the gonioscope.

Schlemm himself found blood in the canal because he examined the eye of a criminal who had been hanged, and in whom, therefore, the veins of the head and neck were most probably greatly engorged.

THE LIGAMENTUM PECTINATUM IRIDIS [1]

The iris, as we shall see, does not arise from the corneo-scleral junction but farther back from the middle of the anterior surface of the ciliary body.

A space is thus left between the sclera and the root of the iris which is filled in by a sponge work of connective tissue trabeculæ known as the ligamentum pectinatum iridis.

This is triangular on meridional section. The apex of the triangle is attached[2] to Descemet's membrane and the posterior layers of the cornea. The inner side lies in the anterior chamber. The outer side of the triangle is in relation anteriorly to the cornea; farther back it forms the inner wall of the canal of Schlemm (Figs. 19, 22, 23).

The base of the triangle is formed by the scleral spur and the ciliary muscle, while the postero-medial angle is, as it were, continued in front of the ciliary body into the root of the iris. Each trabecula on section consists of four layers (Salzmann). Centrally is a mass of collagenous fibrillæ; around this are

[1] The name ligamentum pectinatum iridis is misleading, for, as Fuchs points out, Hueck introduced it because he found that in ungulates on stripping the iris from the sclera the tissue that unites these parts projects in a series of ridges resembling the teeth of a comb (pecten). In the human fœtus up to the sixth month a similar structure is present, but later disappears.

[2] Schwalbe describes the ligament as being attached to the "anterior border ring," which is a circular bundle of connective and elastic fibres placed in front of or in the termination of Descemet's membrane.

elastic fibres then comes a ring of hyaloid material similar in structure and in part continuous with Descemet's membrane This again is covered by endothelium (Fig 25)

The trabeculæ of that portion which lies next the anterior chamber and

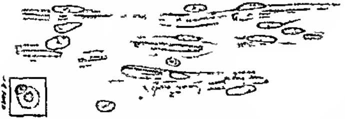


FIG 25 — DETAIL OF LIGAMENTUM PECTINATUM (in Figs 22 23) UNDER HIGHER MAGNIFICATION (ABOUT 800) TO SHOW THE FOUR LAYERS OF WHICH EACH TRABECULA CONSISTS (INSET CROSS SECTION)

passes into the root of the iris (uveal part of lig pect iridis) are much finer than the remainder (scleral part of lig pect iridis) and in them the elastic fibres are absent

The holes in the sponge are known as the spaces of Fontana and are in relation on the outer side with the canal of Schlemm and on the inner communicate with the anterior chamber

THE VASCULAR TUNIC OR UVEAL TRACT

The vascular tunic consists from behind forwards of the choroid ciliary body and iris all continuous with each other

This continuity can easily be made out if the cornea and sclera be carefully dissected off the underlying structures Such a dissection would show a dark brown sphere attached to the optic nerve behind and having a central hole, the pupil in front

On account of the similarity to a grape (uva) of the dark sphere hanging on the optic nerve as on a stalk the middle coat of the eye has received the name of uvea or uveal tract (Fuchs)

THE CHOROID

The choroid is the most posterior part of the vascular coat of the eye It is the homologue of the pia arachnoid and just as the latter serves to nourish the brain, so the choroid nourishes the outer part of the retina It is a thin membrane, extending from the optic nerve to the ora serrata that is the jagged line where the retina ends It is very difficult to estimate the thickness of the choroid for it consists largely of vessels—it has been compared to the corpus cavernosum—and hence diminishes in thickness on enucleation and as the result of fixation But it is thicker posteriorly (about 0 22 mm) than anteriorly (about 0 1 mm) and is especially thick in the macular region (Fig 76)

Its inner surface, which can be examined by removing the vitreous and

retina after opening the eye, is smooth and brown On separating the choroid from the sclera on the other hand, the outer surface of the former is found to be rough and shaggy

The choroid is firmly attached to the margin of the optic nerve, and slightly at the points where vessels and nerves enter it

Structure —The choroid consists mainly of blood vessels, but on either side of these is a non vascular layer On the outer side, i e nearest the sclera, is the *lamina suprachoroidea,* and on its inner side the structureless *membrane of Bruch* The vessels of the choroid are classically described as being arranged

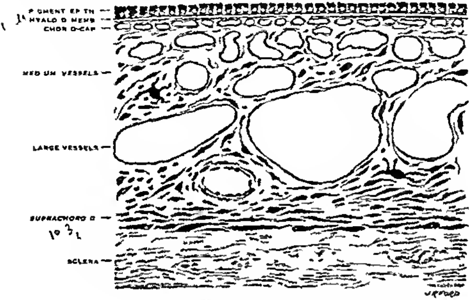


FIG 16 —CHOROID TRANSVERSE SECTION

(After Fuchs and Author's preparation)

in three superimposed strata—the largest being nearest the sclera and the smallest, the capillaries called the *chorio capillaris* towards the retina

Thus we may divide the choroid into five layers, which from without inwards are as follows

1 *The suprachoroid* or lamina fusca is some 10 35 µ in thickness It consists of flattened laminæ closely applied to each other which limit potential spaces These become evident pathologically when the suprachoroid is distended with fluid It is then seen that the laminæ join each other at acute angles at certain points and then separate again, giving the whole the appearance of a grill

The laminæ consist of protoplasmic plaques containing nuclei Schwalbe taught that these plaques were covered by an endothelial layer limiting lymphatic spaces but this is now held to be very doubtful (Redslob) The laminæ are tightly adherent to each other around the places where the vessels pass through them They are also more tightly adherent to each other posteriorly than

anteriorly Hence it is in the anterior portion that a detachment of the choroid usually takes place

The laminæ are traversed by criss crossing and anastomosing elastic fibres

The chromatophores here are more stunted with shorter processes than those in the vessel layer They are more pigmented posteriorly and may be poor in pigment anteriorly The nucleus is always non pigmented The chromatophores spread out in the plane of the surface of the choroid and are thus only seen properly in a flat section (compare Figs 26 and 27)

Unstriped muscle fibres are also found These are more numerous in front of the equator where they tend to form star shaped figures or *muscle stars*

On separating the choroid from the sclera this layer divides, part of it adhering to the former, part to the latter It is this fact that gives the outer surface of the choroid its shaggy appearance

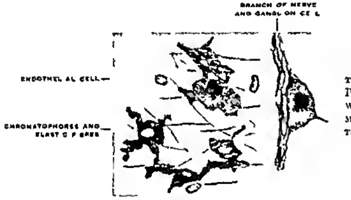


FIG 27 —ELEMENTS OF THE SUPRACHOROID TEASED PREPARATION STAINED WITH MALLORY'S PHOSPHOMOLYBDIC ACID HÆMATOXYLIN × 300

(From Salzmann.)

The suprachoroidal space contains the long and short ciliary arteries and nerves The nerves break up into smaller and smaller branches, which eventually supply the choroid At the points of division of the nerves are placed multipolar ganglia which are probably vasomotor in function (Fig 27)

2 and 3 *The Layer of Vessels* —Classically this layer is divided into two

(*a*) The layer of large vessels (Haller's layer)

(*b*) The layer of medium sized vessels (Sattler's layer)

But while it is possible in places so to separate them usually one cannot do so owing to the irregularity of their distribution

The larger vessels are external and tend to diminish in size as we go towards the chorio capillaris The innermost of them are arterioles which join the capillaries by oblique branches and receive oblique veins from them.

As regards the large vessels the arteries are deep posteriorly but more anteriorly they are superficial In fact in the greater part of the choroid only veins are found next to the lamina fusca

The veins are largest posteriorly especially in the macular region and where

they join the venæ vorticosæ after undergoing an ampullary dilatation No choroidal vein is supplied with valves

The Stroma consists of loose ~~collagenous~~ tissue containing numerous elastic fibres and is especially characterised by the presence of pigment cells or chromatophores These are variable in number, depending on the part of the choroid, the age of the individual his race and general pigmentation The region round the optic nerve is richest in these cells The chromatophore consists of a body and processes The body may be stumpy or elongated and the process long or short, or the whole may be star shaped The cells spread out for the most part in a plane parallel to the surface of the choroid and are therefore, best seen in a flat section Hence one only infrequently comes across a whole pigment cell in a vertical section This is especially true of the suprachoroid

The pigment occurs in the form of rounded dark brown granules smaller than those of the pigment epithelium It is found in the body and processes but the nucleus is always free of pigment The cells usually anastomose with each other so as to form a syncytium but may be found isolated

4 *The Chorio capillaris* consists of capillaries of wide bore (Figs 40 47) packed closely together *They nourish the outer part of the retina* Unlike the other vascular layers, the chorio capillaris contains no pigment Indeed, it is obvious, on looking at any section of the normal choroid, *that it is more pigmented ~~towards its outer than its inner side~~*—

The chorio capillaris ends at the ora serrata, whereas the other layers continue on into the ciliary body.

The capillaries of the chorio capillaris are much wider than elsewhere and show many sac like dilatations They form a net which is densest i e with the smallest meshes, at the macula. Also here the capillaries have the widest bore and so ensure the richest blood supply to the cones of the area centralis Towards the periphery the meshes are larger and tend to be more and more elongated

5 *The Membrane of Bruch, or the lamina vitrea* as it is also called is a thin structureless membrane, 1 5μ in thickness, placed next the pigment layer of the retina, which indeed used to be regarded as belonging to the choroid, since it remains adherent to the membrane when the rest of the retina is removed or detached

The lamina vitrea really consists of two sheets, the outer (elastic lamina) belonging to the choroid, being mesodermal in origin while the inner (cuticular lamina) is secreted by the retinal epithelium and thus ectodermal Normally this division is difficult to make out, but pathologically and by special stains it can be demonstrated (Fig 47) When the two portions separate either pathologically or as an artefact, fine fibrils can be seen traversing the potential space between them As will be seen later the layers do separate at the ora serrata, and in the ciliary body a well marked layer of connective tissue is interposed between them (Figs 31, 32)

The elastic mesodermal portion when cut, folds up and becomes wavy. It consists of densely matted connective and elastic tissue. This is continuous with the choroidal stroma between the capillaries of the chorio capillaris.

It thus comes about that in a flat section of the region the blood of chorio capillaris appears to run in channels separated by islands of connective tissue (Fig. 40). It also follows from the above that the elastic portion of the lamina vitrea may be regarded not as an isolated membrane but as the terminal expansion of the choroidal stroma (Redslob).

Posteriorly the retinal (cuticular or protoplasmic) portion ends with the pigment epithelium while the mesodermal portion continues inwards to reach the neuroglial border tissue of the optic nerve (Fig. 159) or the actual nerve fibres themselves (Salzmann). Here it terminates in a recurved end.

THE CILIARY BODY

If the eyeball is bisected antero-posteriorly and the vitreous lens and retina removed, we see the choroid ciliary body and iris in continuity.

The choroid, as we have seen, extends up to the ora serrata—that is, the rough jagged line where the retina has been torn away anteriorly. Beyond this the ciliary body starts, and can be easily recognised by the fact that it is black, whereas the choroid is brown. If we examine the inner surface of the ciliary body we see that usually the part just beyond the ora serrata is smooth *to the naked eye* and hence is known as the *pars plana or orbiculus ciliaris*.

Under low magnification however one sees the striae ciliaris (of Oscar Schultze) in the pars plana. These are slight dark ridges which run parallel with each other from the teeth of the ora serrata to the valleys between the ciliary processes (Fig. 28).

Also there is often a dark band just in front and following the indentations of the ora serrata (Fig. 28). This marks the posterior attachment of the zonule of Zinn.

Farther forward the inner surface presents about seventy longitudinal ridges of various sizes. These ridges are the *ciliary processes*, and are lighter in colour than the valleys between them. The region in which they occur is called the *corona ciliaris*[1] (Fig. 28).

The whole ciliary body forms a ring whose width is 5.9 mm. on the nasal side and 6.7 mm. on the temporal; of this the corona ciliaris takes about 2 mm.

On sagittal section (Fig. 19) the ciliary body is triangular in form, with its shortest side anterior. The anterior side of the triangle in its outer part usually enters into the formation of the angle of the anterior chamber, but may be covered by the mesh-work of the angle. From about its middle the iris takes origin, and makes with the remaining part of the anterior surface an angle, usually quite acute, which opens in the posterior chamber (Fig. 19).

[1] From cilia (lashes) because of the fine radiating folds (Fuchs).

The outer side of the triangle corresponds to the ciliary muscle and is in relation with the sclera, the suprachoroidal space however coming between them The inner side corresponds to the ciliary processes, and is in relation anteriorly with the fibres of the zonule of *Zinn* which are bathed in aqueous and posteriorly with the vitreous The equator of the lens is about 0 5 mm from the ciliary processes

Structure —From without inwards we find the following layers (1) Lamina fusca or suprachoroidal space (2) ciliary muscle, (3) layer of vessels and the

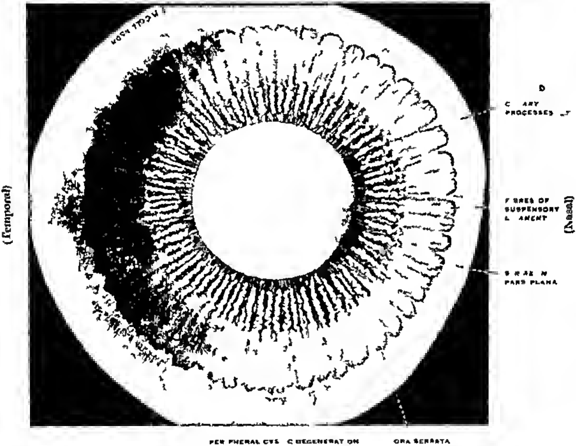


FIG 28—CILIARY BODY SUSPENSORY LIGAMENT LENS AND ORA SERRATA SEEN FROM BEHIND

Note that the teeth of the ora serrata are worst marked on the temporal side where cystic degeneration (shown by the mottled appearance) is best developed

ciliary processes (4) lamina vitrea (5) epithelium (6) internal limiting membrane (Membrana limitans interna ciliaris)

1 *The Lamina fusca* resembles that of the choroid in its posterior part but anteriorly according to Rochon Duvigneaud, is more of a serous space This is due to the fact that the lamellæ and muscle stars gradually lose themselves in the ciliary muscle so that beyond the middle of the muscle the space

usually contains neither of these At times, however, a band does cross this anterior portion and prevents it being involved in the common detachment of the ciliary body, which may occur pathologically or as an artefact

2 *The Ciliary Muscle* in an antero posterior section has the form of a right angled triangle the right angle being internal and facing the ciliary processes The posterior angle is acute and points to the choroid the hypotenuse runs

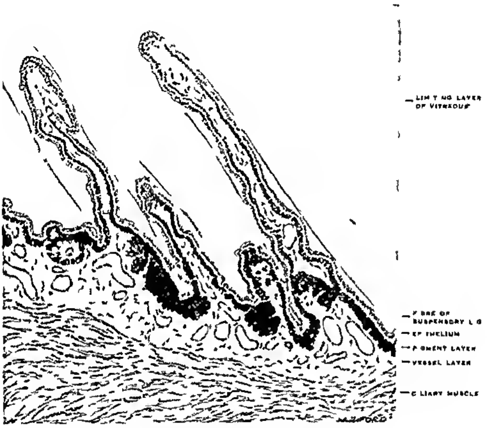


FIG 29 —OBLIQUE SECTION OF THE CILIARY BODY

Note that the pigment does not go to the apex of the main ciliary processes Hence they are white in the living The ones in between however appear black as the pigment reaches to the apex (Author's preparation)

parallel with the sclerotic The form of the whole ciliary body depends on that of the muscle which consists of flat bundles of unstriped muscle, the outermost running antero posteriorly, the inner circularly

The Longitudinal Fibres, also called Brucke's muscle, arise from the scleral spur at the junction of cornea and sclera and run backwards (Fig 10) *It is this*

attachment to the cornea sclera which is the main union between the uveal tract and the fibrous coat of the eye

Some of the muscle fibres are lost in the outer layers of the choroid some can be traced into the suprachoroidea as far as, or even beyond, the equator, while others bend round and are said to become continuous with the circular fibres These oblique junctional fibres have been described as the *radial portion* of the muscle The radial portion lies within the longitudinal fibres It is distinguished from these by the reticular character of its stroma, but is very often difficult to separate from the circular fibres (see Fig 19)

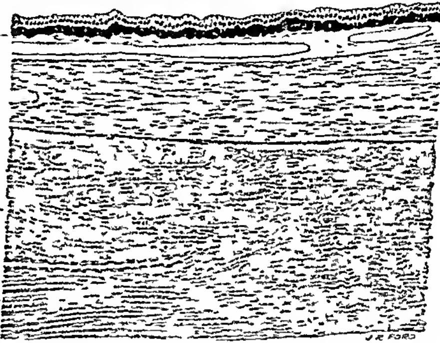


Fig 30 —Ciliary Body (Pars Plana) Antero Posterior Section

(Author s preparation)

The Circular Fibres (or Muller s muscle) occupy the anterior and inner portion of the ciliary body They lie within Brucke s muscle, and run parallel with the margin of the cornea The fibres are thus cut transversely in an antero posterior section The muscle of Müller is not present in the new born but develops after birth Hence it is only after the fifth year with the appearance of this portion of the muscle that the ciliary muscle takes on its triangular appearance (Fuchs) Passing through the muscle are branches of the long posterior ciliary and the anterior ciliary arteries which supply it The venous return is via the ciliary processes to the choroidal veins and partly via the anterior ciliary veins *The circulus arteriosus iridis major* lies in the ciliary body in front of the circular portion of the muscle (Figs 19 23)

The Stroma of the Ciliary Muscle.—In the longitudinal portion the stroma forms thin longitudinal lamellæ which are continuous with those of the suprachoroidal space, from which pigment cells can often be traced into the muscle.

In the radial portion the stroma has a reticular structure, and consists of dense connective tissue in which are found blood vessels, nerves, and, in deeply pigmented eyes, a few chromatophores.

In the circular portion the stroma is looser, and resembles that of the root of the iris, with which it is continuous.

The differentiation between stroma and muscle fibres comes out very well with van Gieson's stain,[1] the former being coloured pink, the latter yellowish green. The stroma is little apparent in the new born and increases with age. In the old it tends to become sclerosed and may undergo a hyaline degeneration which indeed is the fate of all the connective tissue of the ciliary body.

The action of both portions of the ciliary muscle is to slacken the suspensory ligament of the lens. This results in decreased tension on the capsule of the lens, which therefore becomes more convex—as in looking at near objects. According to Thompson (1912) the longitudinal part of the muscle *takes origin* in the epichoroid, and is *inserted* into the scleral spur. He holds that it exerts a *pumping action* on the canal of Schlemm, which is responsible for the drainage of the aqueous from the anterior chamber. The pull of the muscle on the spur opens the canal and sucks in the aqueous, while the elastic tissue around will pull the spur to its normal position and thus tend to empty the canal.

According to Iwanoff the circular fibres of Müller are much better developed in the hypermetropic than in the myopic eye. This accords with the fact that the hypermetropic eye has to accommodate more than the myopic. He also pointed out that normal eyes may show great differences in the relative amounts of the two portions of the muscle.

But Heine showed that if the eye of a monkey, which had been atropised before death, be sectioned its ciliary muscle has the form of the hypermetropic type, whereas an eye similarly treated with eserine has a myopic ciliary muscle.

It is probable that the differences in form of the ciliary muscle (which are present at birth) depend simply on the length of the eye, e.g. the long myopic eye has a long ciliary muscle. The ciliary muscle is supplied by the ciliary nerves. These form a plexus containing ganglion cells on the surface of the muscle. The actual nerve endings are, according to Agababow, motor-nerve endings, vaso-motor endings on the vessel walls, reticular plates for ordinary sensation, and arborisations for proprioceptive sense.

3. *The Ciliary Processes*.—Each ciliary process is a ridge some 2 mm. long and 0.5 mm. high, which becomes wider as we trace it anteriorly, where it ends in an expansion known as the head of the process. Its colour is almost white, which makes it stand out in strong contrast to the deep pigmentation of the valleys between the processes (see Fig. 29).

If we separate two ciliary processes, we see smaller ridges of various sizes between them.

[1] Also with Mallory's triple stain. Muscle fibres are red and connective tissue blue.

The ciliary processes consist essentially of blood vessels (for the most part veins), the continuation forwards of those of the choroid with the exception of the chorio-capillaris It is the most vascular region of the whole eye, and the ciliary muscle takes no part in its formation (Fig 29)

In the pars plana of the ciliary body the vascular layer is much like that of the choroid with which indeed it is directly continuous, but it is not so wide and there is no chorio capillaris (Figs 30 and 31) Since also the artery of supply to the whole region passes through the ciliary muscle, the vessels consist almost entirely of veins which run backwards parallel with each other

The ciliary processes are essentially a great thickening of the vascular layer

4 *The Lamina vitrea*—To the inner side of these vessels is the forward

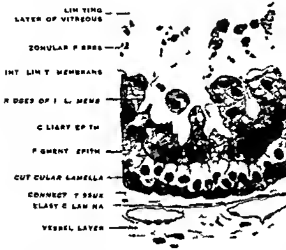


FIG 31 —BLEACHED TRANSVERSE SECTION OF THE ORBICULUS CILIARIS NEAR THE CORONA CILIARIS × 380 (*From Salzmann*)

continuation of the lamina vitrea of the choroid, which, however, has quite a different structure here For as we trace the choroidal lamina towards the ora serrata we find that it splits into two laminæ, the outer elastic and inner cuticular, and by the time we reach the ciliary body a layer of avascular connective tissue is found between the two Also the surface of the inner of the two laminæ is raised into ridges which surround slight depressions and are called the reticulum of Heinrich Muller The depressions form shallow sockets for the cells of the epithelium, which thus get a firmer hold and are better able to withstand the pull of the zonule (Figs 31 32, and 33)

The Stroma of the vascular portion of the ciliary body resembles that of the choroid But the chromatophores are not so plentiful and indeed may disappear entirely in the anterior portion and in the ciliary processes, also the connective tissue, in which are found some elastic fibres, is denser and shows up exceedingly well with van Gieson's stain

5 *The Epithelium* (Pars ciliaris retinæ)—Lining the lamina vitrea are two

layers of cells, the outer of which consists of pigment cells and represents the forward continuation of the pigment layer of the retina But where the rods and cones cease the cells of the pigment epithelium diminish in height and lose their

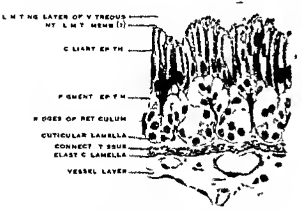


FIG 32 — BLEACHED TRANSVERSE SECTION OF THE ORBICULUS CILIARIS (PARS PLANA) NEAR THE ORA SERRATA × 320

(*From Salzmann*)

pigment processes The cells become much more pigmented so that the nucleus is usually entirely masked

The pigment consists of rounded granules, which are larger and darker than those of the choroid (and retina) Hence the ciliary body (except the corona ciliaris) is darker than the choroid

In certain parts, especially in the anterior portion of the ciliary processes this layer of cells becomes invaginated to form structures which may resemble tubular glands (Fig 32) Treacher Collins,[1] who first described them, believed that they secreted the aqueous

But these "glands" have no lumen, and it is exceedingly doubtful whether they perform this function (See however, p 51)

The *striæ ciliares* and the *dark band* in front of the ora serrata are formed by the pigment epithelium being evaginated into hollows formed by particularly wide meshes of the reticulum of Heinrich Muller

The pigmentation is much less over the ridges of the ciliary processes (Fig 29), resulting in the whitish appearance of this region

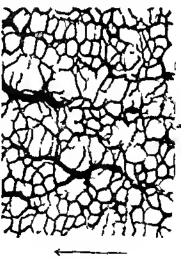


FIG 33 — SURFACE VIEW OF THE RETICULUM OF H MÜLLER IN THE ANTERIOR PART OF THE ORBICULUS CILIARIS STAINED BY MALLORY'S HÆMATOXYLIN × 285 THE ARROW POINTS FORWARDS

(*From Salzmann*)

[1] E T Collins, *Trans of the Ophth Society of the United Kingdom* 1890–1891

The innermost layer of the ciliary body, i e that next the vitreous, consists of non pigmented cells and is continuous at the ora serrata with the nervous layer of the retina. It should be noted, however, that these non pigmented cells are much more firmly united to the pigmented ones than is the retina with its pigment epithelium. *Hence (pathological) detachment of the retina stops at the ora serrata*

The non pigmented cells are flattened just in front of the ora serrata. Farther forwards they are cylindrical and over the ridges of ciliary processes cubical.

It will be seen later on that these two layers are continued forwards behind the iris, and represent the anterior part of the optic cup.

The transition from the non pigmented layer of the ciliary body to the pigmented cells on the posterior aspect of the iris takes place *near*, and not *at*, the root of this membrane (Fig 19)

The cytoplasm of the ciliary epithelium has attracted much attention. Mawas (according to Redslob) has found in the cell refractile granules, mitochondrial formations most marked in the apical portions of the cell, *vacuoles containing crystalloids and lipoid vesicles. He has seen* changes in the position of the nucleus, changes in its form and chromatin content, all characteristics of secretory cells. After depigmentation he finds the same formations in the pigment epithelium. The mitochondria increase after puncture of the anterior chamber. *Diamico has found iron containing granules in the pigment epithelium which makes the* melanin here unique and probably points to a special function of the epithelium. Apart from the mitochondria Schmeltzer has discovered in the cytoplasm of the non pigmented cells, granules which stain blue with indo phenol. All these facts appear to point to a secretory *function of the ciliary epithelium*

However this may be, the formation of the aqueous humour is still much disputed.

It would seem that the tissue fluid of the ciliary processes, which comes from the capillaries, has the same composition as the tissue fluid elsewhere in the body. It is changed *into aqueous in its passage through the ciliary epithelium which takes up certain of its* constituents.

6 *The Internal Limiting Membrane* (Membrana limitans interna ciliaris) — On the inner side of the non pigmented epithelium is the membrana limitans interna ciliaris, the continuation forwards of the internal limiting membrane of the retina. It is a very thin membrane which is absent over the posterior part of the orbiculus ciliaris.

The Iris

The iris is the most anterior portion of the vascular tunic of the eye. It differs from the choroid and ciliary body in being placed in a more or less frontal plane. It is a thin circular disc corresponding to the diaphragm of a camera and is perforated near its centre, usually slightly to the nasal side, by a circular aperture called the pupil.

This varies greatly in size under different conditions, being, for instance, pin point in bright sunlight and widely dilated in the dark. It thus regulates the amount of light which reaches the retina.

The iris is attached at its periphery or root to the middle of the anterior surface of the ciliary body. It will be noted that it does not arise from the

corneo scleral junction but farther back and that therefore *not only does part of the sclera* ACTUALLY COME INTO THE ANTERIOR CHAMBER OF THE EYE (see p 105) BUT AS A RULE PART OF THE CILIARY BODY AS WELL

The root is relatively thin and explains the frequency with which it tears away from the ciliary body (irido dialysis) as the result of contusion injuries

The iris gets thicker as we approach the collarette which is at the thickest part and then thins again to the pupil

The pupillary margin rests and is supported on the front of the lens which is farther forwards than the origin of the iris from the ciliary body The iris therefore inclines forwards from its attached to its free margin (Fig 19)

The iris thus has the shape of a cone whose apex is cut off at the pupil *When the lens is absent the cone is flattened and the iris becomes tremulous*

The iris forms a curtain dividing the space between the cornea and the lens into the *anterior* and *posterior* chambers of the eye

Macroscopic Appearance of the Iris

The anterior surface of the iris

The ciliary zone presents a series of radial streaks running parallel to each other These are straight when the pupil is small and wavy when it is dilated

If the iris is stuffed with pigment as in the dark races of mankind the anterior surface appears smooth homogeneous velvety the structure being masked by the melanin

Near the pupillary margin we find a series of ridges which roughly form a circle also formed by vessels (namely the circulus vasculosus iridis minor [1])

The surface of the ridges is marked by a zigzag line which represents the attachment of the pupillary membrane This line called the collarette divides the anterior surface of the iris into two zones—the outer, the *ciliary zone* and the inner the *pupillary zone* which often differ in colour

In the region of the circulus minor are many pit like depressions called the crypts of Fuchs At these points as will be seen later the anterior endothelium and border layer of the iris are deficient so that fluid can get quickly in and out of the iris—for instance during contraction and dilatation of the pupil

Similar crypts are present near the root of the iris but are small and not seen in the living eye This is due partly to their size and partly because they are concealed by the margin of the sclera which projects in front of them It is only in blue eyes especially in children that the peripheral perforated zone becomes apparent as a dark almost black circle close to the root of the iris (Fuchs)

In the new born neither collarette nor crypts are present They develop later

[1] See Slit lamp Appearances p 168

At the pupillary margin there is a fringe of black pigment, better marked when the pupil is small or is thrown into relief by the white of an opaque lens. Under the magnification of a loupe it is seen to have a beaded appearance. It represents the anterior edge of the optic cup (Fig. 34).

At times when the pupillary zone has an especially delicate structure the sphincter pupillæ can be seen as a whitish band about 1 mm. in width close to the pupillary border (Salzmann).

The inner part of the ciliary zone is fairly smooth, but near the outer part one

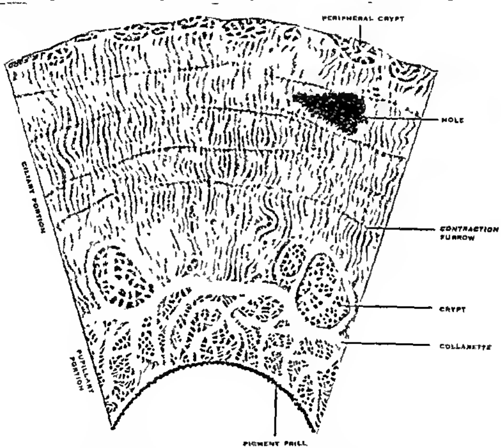


FIG. 34.—THE SURFACE ANATOMY OF THE FRONT OF THE IRIS.

sees several concentric lines which become deeper as the pupil dilates. They are, in fact, *contraction* furrows corresponding to the folds in the palm of the hand.

At the bottom of the furrow there is less pigment than elsewhere in the stroma, so that they are best seen in a dark iris with a contracted pupil (Fuchs).

The posterior surface of the iris appears dark brown and smooth to the naked eye. With the loupe, however, the following fine radial and circular furrows can be made out :

Schwalbe's Contraction Folds are numerous little radial furrows which com-

mence 1 mm from the pupillary border wind round this notching it, and giving it its crenated appearance

Schwalbe's Structural Furrows—so called because they are present in the vessel layer as well—start about 1·5 mm from the pupillary margin and narrow and deep at first become broader and shallower as they approach the ciliary margin

The Circular Furrows are finer than the radial They cross the structural

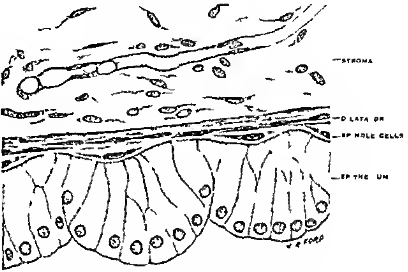


FIG 35.—BLEACHED SECTION OF IRIS (POSTERIOR PORTION)

(Author's preparation)

furrows at regular intervals and are due to the difference in thickness of the pigment epithelium

Structure.—The iris consists from before backwards of the following five layers

1 The anterior endothelium
2 The anterior limiting (border) layer
3 The stroma
4 The posterior membrane
5 The posterior epithelium

1 *The Anterior Endothelium*.—While it is present as a continuous layer in certain animals it is still disputed whether an anterior endothelium exists in the human Wolfrum believes that it does not or at any rate only as islands It is extremely difficult to demonstrate and is certainly not present in the diagrammatic way illustrated in many textbooks of anatomy In animals it has been demonstrated on surface view by means of silver nitrate

My own preparations stained with Mallory's triple stain appear to indicate that an anterior endothelium is present in the human

2 *The Anterior Limiting Layer* (Figs 19, 23) is really a condensation of the anterior part of the stroma It consists of a dense matting produced by anastomosing and intertwining processes of connective tissue and pigment cells In it are found *obliterated* blood vessels and numerous nerve endings The connective tissue cells are star shaped have the characteristics of primitive mesenchyme cells, and spread out mostly parallel to the surface The anterior limiting layer is deficient at the crypts and much thinned at the contraction furrows On it depends the definitive colour of the iris In the blue iris the anterior limiting layer is thin, and has only a few pigment cells, in the brown iris it is thick and densely pigmented

3 *The Stroma* consists of loose[1] connective tissue containing pigment cells in which are embedded the following structures

(*a*) The sphincter pupillæ muscle,
(*b*) The vessels and nerves of the iris
(*c*) The pigment cells

It is curious that although the iris gapes readily when cut it contains very few elastic fibres Lieto Vollaro has shown that they are situated for the most part in the posterior part of the stroma and have a radial direction Some elastic fibres are also found between the sphincter and dilatator pupillæ

(*a*) *The Sphincter pupillæ* consists of a flat bar of intertwining plain muscle fibres whose predominant direction is circular, separated by connective tissue containing vessels It is 1 mm broad, forming a ring all round the pupillary margin near the posterior surface of the iris It is derived from ectoderm and its inner edge comes close to the pupillary zone of pigment cells which gave it origin *When it contracts it constricts the pupil, and tends to pull the edge of the pigment on to the anterior surface of the iris* It is supplied by the 3rd cranial nerve viâ the short ciliaries

The sphincter muscle does not lie loose in the stroma tissue Each portion adheres firmly to surrounding structures by vessels and by radial bundles of connective tissue Hence *after an iridectomy the portion of the sphincter remaining does not contract up and the pupil can still react to light*

There are also two or more definite junctional fibres between the dilatator and sphincter (see below)

(*b*) *The Vessels* form the bulk of the iris, they run radially for the most part,

[1] The stroma according to Fuchs may be divided into three portions—anterior (including the anterior limiting layer) posterior denser layers, and a middle layer the cleft of Fuchs consisting of very loose tissue This spongy tissue forms the floor of the crypts It enables the anterior layer to glide on the posterior in dilatation and contraction of the pupil The vessels tend to run either anterior or posterior to the cleft of Fuchs The posterior layer is less dense than the anterior Here the connective tissue and pigment cells are attached vertically or obliquely to the dilatator, they also surround the sphincter and are placed radially along the blood vessels

giving rise to the streaks which can be seen on the anterior surface Their course is sinuous to allow for movements of the iris They straighten out as the pupil constricts and become more wavy as it dilates

At the root of the iris and near the pupillary margin however there are circular anastomoses known as the Circulus vasculosus iridis major and minor

The former is arterial and lies actually in the ciliary body in front of the circular portion of the ciliary muscle (Figs 19 and 23) The latter is arterial and venous hence the name circulus *arteriosus* is not correct

As regards the origin of these vessels they are derived from the long and anterior ciliary arteries in the following way

The long ciliary arteries—two in number—pierce the sclerotic on the outer and inner sides of the optic nerve They run in the suprachoroidal space between choroid and sclera often grooving the latter Just behind the attached margin of the iris each divides The branches so formed anastomose with each other and the anterior ciliary arteries (which come from the muscular vessels and pierce the sclera) to form a ring known as the Circulus iridis major (see also p 59)

From here radial branches run towards the pupil but near its edge arterial and venous anastomoses takes place to form the Circulus *vasculosus* iridis minor

The nerves are derived from the long and short ciliaries These follow the course of the corresponding arteries piercing the sclera around the optic nerve and running in the space between choroid and sclera Some end in the vessels of the uveal tract others supply the various intrinsic muscles of the eye They are curious in having many gangliform enlargements

(c) *The Pigment Cells* (chromatophores) are of two kinds

The one type of chromatophore is a slender cell with delicate processes which anastomose with those of neighbouring cells They are filled with rounded pigment granules which may be honey coloured or brown The oval nucleus is always non pigmented Apart from being found in the anterior and posterior layers around the vessels and sphincter the chromatophores form at the ciliary margin a close chain uniting the dilatator to the surface of the iris (Redslob)

(b) In the neighbourhood of the sphincter pupillae and rarely near the ciliary border one finds the so-called clump cells They are rounded pigment cells without processes Their pigment consists of large round and very dark granules which resemble those of the cells of the posterior surface of the iris from which, in fact they are derived (Fleching Lauber) (Fig 19) They often retain their pigment in blue and partially albinotic irides and in these cases can be seen easily with the slit lamp

4 *The Posterior Membrane* or membrane of Bruch consists of a thin layer of plain muscle fibres which, like the sphincter are derived from the anterior layer of the optic cup and hence ectodermal in origin They constitute the Dilatator pupillae muscle and are really the processes of the spindle cells belonging to the next layer (Fig 35)

Close to the edge of the pupil the dilatator fuses with the sphincter also about midway along the length of the sphincter the dilatator sends a few junctional fibres accompanied by pigment (Fuchs spur)

Von Michel s spur is a similar bundle of dilatator fibres accompanied by pigment which is attached to the peripheral border of the sphincter At the iris root a third spoke of dilatator fibres (Grunert s spur) runs into the iris stroma The dilatator is continued into the ciliary body (Fig 23) where it takes origin.

When it contracts it draws the pupillary margin towards its origin and thus dilates the pupil The dilatator is poorly developed in the new born in whom it is difficult to dilate the pupil fully with a mydriatic It is supplied by the sympathetic via the ciliary nerves

It should be mentioned here that the presence of these dilatator fibres is denied by many As Grynfelt and others have shown they can only be demonstrated when the iris is bleached These observations together with the experiments of Langley and Anderson put the existence of the dilatator beyond dispute

5 *The Posterior Epithelium* consists of two layers of cells which are derived from the most anterior part of the optic cup Being highly pigmented they are difficult to make out except in albinotic eyes or in preparations which have been decolorised The anterior layer consists of flat spindle cells the posterior layer of large polyhedral or cubical cells with comparatively small round nuclei

Dilatator fibres are the processes of the spindle cells which have thus only partially developed *into muscle* In the other ectodermal epithelial muscle the sphincter *on the other hand—the cell—*has undergone complete differentiation

The pigment granules are dark brown and for the most part round but some are rod-shaped like the retinal pigment in lower mammals (Parsons)

After lining the back of the iris the pigment epithelium curls round the pupillary margin where it gives rise to the black fringe which can be seen with the naked eye (Figs 19 and 34)

Just as the pigment epithelium of the retina adheres firmly to the lamina vitrea of the choroid in a detachment of the retina so when the posterior of the two layers at the back of the iris remains adherent to the lens in the rupture of a posterior synechia the anterior remains attached to the posterior membrane

Thus it will be seen that the iris has fundamentally the same structure as the ciliary body It consists of uveal and retinal portions The uveal portion is anterior The retinal portion is represented as in the ciliary body by two layers of cells but here both are pigmented Here al o the ectodermal cells have become metamorpl osed *into* muscle fibres

The Colour of the Iris —Most babies belonging to the white [1] races of mankind

[1] In the dark races tl e ir s stroma contains p gment at birth and hence in the new born the iris is not blue (Usher)

are born with blue eyes (Fuchs) The reason for this is that the dark pigment on the posterior aspect of the iris seen through the translucent stroma (which as yet has no pigment of its own) appears blue, just as the veins (although the blood in them is of a port-wine colour) look blue through the skin As time goes on, pigment is deposited in the anterior limiting layer and the stroma, and, varying with the amount so laid down, the colour changes If little is deposited, the eye remains blue or grey—if there is much, the eye becomes brown

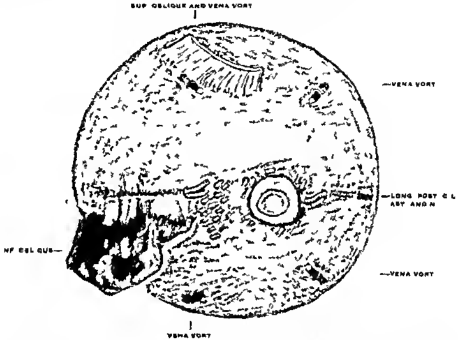


FIG 36—THE GLOBE OF THE EYE FROM BEHIND

To show the attachment of the oblique muscles and optic nerve Also the points of entry of the posterior ciliary arteries and nerves and exit of the venæ vorticosæ Note that the inferior oblique is fleshy almost up to its insertion and that the venæ vorticosæ *appear* to converge towards a common trunk

THE CILIARY ARTERIES

The ciliary arteries comprise

(1) The short posterior ciliary arteries

(2) The long posterior ciliary arteries

(3) The anterior ciliary arteries

These supply the whole of the uveal tract the sclera and the edge of the cornea with its neighbouring conjunctiva

(1) The Short Posterior Ciliary Arteries.—The posterior ciliary arteries usually come off the ophthalmic as two trunks while the artery is still below the optic nerve These divide into some 10–20 branches which, running forwards, sur-

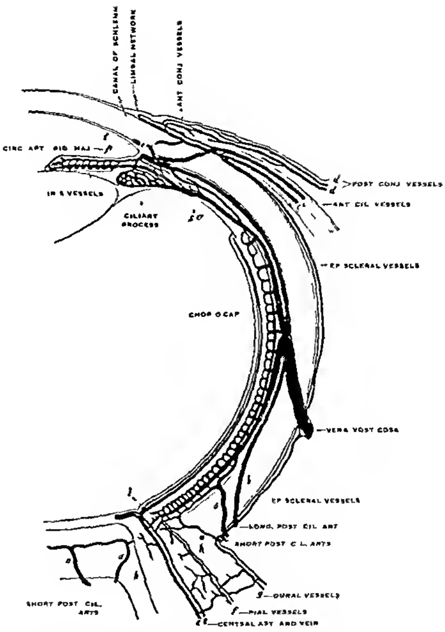


Fig 37 —The Blood Supply of the Eye (*From Leber*)

k = branch of short posterior ciliary artery to the optic nerve
l = anastomoses between choroidal and central vessels In the case of the artery this is capillary only
s = vein from ciliary muscle to vena vorticosa
t = branch of anterior ciliary vein from ciliary muscle
o = recurrent artery

round the nerve and pierce the eyeball around it The majority of these constitute the short posterior ciliary arteries while the two which pierce the sclera to the inner and outer side of the nerve respectively are called the *long ciliary arteries*

The majority and largest of the short posterior ciliaries, after giving branches to the sclera, pierce it (the sclera) in the region of the posterior pole of the eye (and macular region), i e lateral to the optic nerve (Fig 30) A smaller number and of smaller size pierce the sclera all round but closer to the optic nerve The canals in the sclera through which they pass are almost directly antero posterior The space left free is filled with loose tissue which is a prolongation of the supra choroid Some of the short ciliaries anastomose with each other to form the circle of Zinn (see p 99) which goes to supply the optic nerve, the papilla and the neighbouring retina

(2) **The Two Long Posterior Ciliary Arteries**—The two long posterior ciliary arteries (nasal and temporal) pierce the sclera on either side of the optic nerve somewhat farther anteriorly than the short ciliaries Each passes through the sclera in a canal some 4 mm long This canal runs outwards, at first very obliquely, then bends forwards at 45° to reach the interior of the eye more rapidly (Redslob) Each artery is accompanied by a ciliary nerve which later enters the choroid The mouth of the canal is very wide and may contain in addition to the above a few short ciliary arteries, and arteries, nerves, and veins to the sclera (Leber and Figs 76, 38) The space left free in the canal is filled with loose connective tissue The canal gets narrower as we trace it forwards, but widens again slightly at its anterior end where it terminates in a sharp border The arteries reach the suprachoroidal space and in it run forwards in the horizontal meridian on either side Their course here can be followed quite easily from the outside because, owing to the translucency of the sclera, they appear as dark lines (Fig 30). Without having given off any branches they reach the ciliary muscle, where they divide into two branches which enter the substance of the muscle and at its anterior end anastomose with each other and with the anterior ciliary arteries to form the circulus iridis major.

FIG 38—TRANS SECTION OF THE CANAL FOR THE LONG POSTERIOR CILIARY ARTERY AND NERVE

Note the accompanying nerves and vessels The veins are scleral veins and do not correspond to the long ciliary artery

(3) **The Anterior Ciliary Arteries** —The anterior ciliary arteries do not come directly from the ophthalmic but are derived from the arteries to the four recti muscles from whose tendons they emerge Usually two arteries emerge from each tendon except that of the external rectus from which only one comes These arteries pass anteriorly in the episclera give branches to the sclera, corneal margin and conjunctiva and pierce the sclera not far from the corneo scleral junction the spot being not infrequently marked by pigment

The canals through which they pass run almost directly inwards

The anterior ciliary arteries enter the ciliary muscle then anastomose with the long posterior ciliaries to form the circulus iridis major (see also below)

THE VEINS OF THE CILIARY SYSTEM OF VESSELS

(1) **The Venæ Vorticosæ** (or posterior ciliary veins) usually four in number (two superior and two inferior) pierce the sclera obliquely on either side of the superior and inferior recti muscles some 6 mm behind the equator of the globe The superior veins leave the eye farther back than the anterior while the outer veins tend to be nearer the mid vertical plane than the inner The superior lateral vein is the most posterior (8 mm behind the equator) and is in close relation to the tendon of the superior oblique (Fig 30) The inferior lateral vein is the most anterior (5 5 mm behind the equator) Often there are more than four veins

At times especially in myopic eyes they may leave the globe much farther back, even close to the optic nerve

Their passage though the sclera is as oblique as that of the long posterior ciliary arteries The canal some 4 mm long is directed posteriorly and towards the mid vertical plane of the eye so that the four veins appear to converge towards a common parent trunk (Leber and Figs 37 30) Their course in the canals can be followed from outside for owing to the translucency of the sclera they appear as dark lines The veins may divide in the canals so that the emergency vessels may number six or more At its choroidal end the vein has an ampulliform dilatation

The two superior venæ vorticosæ open into the superior ophthalmic vein either directly or via its muscular or lacrimal branches

The two inferior veins open into the inferior ophthalmic vein, or into the anastomotic branch this gives to the superior ophthalmic vein

[1] The recti muscles are not in contact with the exit of the venæ vorticosæ but according to Fuchs and Weichelbaum it is quite possible that the two oblique muscles may at times compress the two outer veins especially the lower of these This is especially liable to occur when the eyes are looking downwards and during convergence The stasis so produced may play some part in the increase in myopia as the result of near work

See Leber in Graefe Saemisch ii part 2

Between the vein and the sclera is a lymphatic space which is filled with a prolongation of the suprachoroid After its exit from its canal the walls of the venæ vorticosæ become much thicker and develop a well marked muscularis

(2) **Small branches from the sclera** correspond to the scleral branches of the short ciliary arteries They only carry blood from the sclera—none from the choroid—and are therefore smaller than the corresponding arteries

(3) **The anterior ciliary veins** are like the arteries tributaries of the muscular veins Since they only carry blood from the ciliary muscle they are smaller than the corresponding arteries

Thus it will be seen that the arteries and veins of the ciliary system of vessels do not correspond either in their number in their course or in their method of branching Moreover very often the arteries are larger than the veins which is unusual elsewhere in the body Also the veins like those of the retina have no valves

THE BLOOD SUPPLY TO THE UVEAL TRACT

With regard to its arterial supply the uveal tract is divided into two more or less distinct parts

(1) The short posterior ciliaries supply the choroid

(2) The long posterior ciliaries and the anterior ciliaries supply the iris and ciliary body But the anterior part of the choroid is supplied by the recurrent arteries and these anastomose with the short ciliaries

The venous return is quite different being via the venæ vorticosæ for practically the whole uveal tract The anterior ciliary veins only carry off the blood of the ciliary muscle These two systems of veins do communicate This is seen in the compensatory changes in disturbances of circulation Thus for instance in glaucoma in which the outflow of venous blood through the venæ vorticosæ is impeded we see the anterior ciliary veins taking on their work and carrying off larger quantities of blood than usual

The Arterial Supply of the Choroid—The short ciliary arteries after piercing the sclera lie at first in the suprachoroid surrounded by pigmented tissue They pass forwards in a wavy manner and then gradually penetrate the choroid They divide dichotomously and eventually break up into the capillary network or chorio capillaris The larger branches reach to the ora serrata The arteries in their course forwards are much straighter than the veins which are very wavy and hence are cut more often in sections which makes them appear much more numerous than they really are

The number of vessels in the macular region is much greater than elsewhere so that here in a well injected specimen an almost inextricable mass of vessels of various sizes is seen which much resembles the corpora cavernosa The veins certainly do anastomose freely but the arteries rarely so that the apparent anastomoses of arteries that one sees with the ophthalmoscope are usually due to the crossings of the vessels since the walls of the latter are invisible

The anterior part of the choroid is supplied by the *recurrent ciliary arteries* These arise in the ciliary body from the circulus iridis major and from the long posterior ciliary and anterior ciliary arteries before these have been joined to form the circle Of varying number (10 20) and size they run backwards between the numerous parallel veins of the orbiculus ciliaris They divide dichotomously and break up into the chorio capillaris of the anterior part of the choroid and also anastomose with the short posterior ciliaries These anastomoses are the only ones between the arteries of the choroid on the one hand and the ciliary body and iris on the other (Fig 37)

FIG 34—FLAT SECTION OF THE CHOROID AT THE MACULA (ZENKER MALLORY'S TRIPLE STAIN) TO SHOW ANASTOMOSING CHOROIDAL VEINS

Note that the arteries have a well developed muscular coat and generally thicker walls than the veins

(Author's preparation)

The chorio capillaris extends as does the choroid from the optic nerve to the ora serrata

The Arterial Supply of the Ciliary Body and Iris

The recurrent arteries and the arteries to the ciliary muscle arise from the circulus major and from the long posterior ciliaries and anterior ciliaries before these have united to form the circle They may form a second arterial circle in the ciliary muscle called the circulus arteriosus musculus ciliaris (Leber)

The circulus iridis major lies not as its name implies in the iris but in the ciliary body in front of the circular portion of the ciliary muscle (Figs 19 and 23) The arteries of the ciliary muscle consist of a great number of arteries which divide dichotomously and break up into a fairly dense capillary net which differs markedly in appearance from that of the ciliary processes

The arteries of the ciliary processes come from the circulus iridis major often in common with those of the iris Each ciliary process usually receives one artery but a larger branch may supply two or even three neighbouring processes These arteries like those of the iris pierce the ciliary muscle They enter the ciliary process anteriorly and soon break up into numerous branches which anastomose with each other and break up into a dense network of wide capillaries which form the main mass of the ciliary processes From these come the veins which constantly anastomosing with each other pass backwards to the venæ vorticosæ being placed to the inner side of the ciliary muscle (Fig 30)

The arteries of the iris come from the circulus major as numerous branches, often in company with those of the ciliary processes They enter the iris at the site of attachment of a ciliary process, usually several to each process (Leber), and in the intervals between the peripheral crypts They run with occasional anastomosis radially from the ciliary to the pupillary margin With the pupil small their course is more or less straight, but becomes more and more wavy as the pupil dilates They have, like the veins, thick walls in comparison with their calibre

During life the branches of the vessels are seen as radial streaks united here and there with each other, more visible in the blue iris, less so in the brown where they can only be made out in the ciliary portion and not at all in the densely pigmented irides of the coloured races Only in albinotic eyes is the blood column visible and even here only very slightly At the collarette, which marks the place where the fœtal papillary membrane was attached a few anastomoses take place (These, with the corresponding venous anastomoses, make an incomplete circle A circulus arteriosus iridis minor therefore does not exist An attempt at a circulus vasculosus only is present) The majority of the vessels pass directly to the papillary margin where after breaking up into capillaries, they bend round into the commencement of the veins

There is a dense capillary plexus around the sphincter and another less dense in front of the dilatator The capillaries form a loose network in the ciliary region and are but little in evidence, or absent, in the anterior limiting layer

The Veins of the Uveal Tract

The venæ vorticosæ drain the blood from all parts of the choroid No veins leave the eye in the region where the posterior ciliary arteries enter (except very rarely in myopic eyes) The small veins from the optic nerve head, and sometimes from the retina, also join the choroidal veins The stems of the venæ vorticosæ undergo ampulliform dilatation just before they enter the sclera They are joined by radial and curved branches which give the whole a whorl like appearance—apparent on the outer surface of the choroid even in uninjected specimens It is this appearance which is responsible for the name venæ vorticosæ Of the branches which drain the posterior part of the choroid those that come from the region of the optic nerve are longest and run more or less directly to the venæ vorticosæ The more they enter the vein from the sides, the shorter and the more bent are they

The anterior tributaries of the vorticose veins come from the iris, the ciliary processes, the ciliary muscle, and the anterior portion of the choroid

The veins run parallel with each other in the pars plana and then at the ora serrata turn obliquely towards the corresponding vena vorticosa, taking up branches from the choroid as they do so

The veins of the ciliary muscle mostly pass backwards to join the parallel veins coming from the ciliary processes. A few, however, pass forwards and pierce the sclera to join the anterior ciliary veins.

The veins of the ciliary processes pass backwards as a series of parallel anastomosing vessels in the pars plana to the inner side of the ciliary muscle to reach the choroid and join the venæ vorticosæ.

The veins of the iris run like the arteries, anastomosing with each other. Arrived at the ciliary border they enter the ciliary body and join the veins of the ciliary processes, so passing to the venæ vorticosæ.

Structure of the Choroidal Vessels.—*The arteries* show a well developed muscularis with an adventitia made up of fibrillar collagenous tissue containing thick elastic fibres.

FIG. 40.—FLAT SECTION OF THE CHORIO-CAPILLARIS.

Note the islands of connective tissue (staining denser at the periphery than at the centre) between the streams of corpuscles in the capillaries.

According to Wolfrum the arterioles possess muscular fibrils with long processes which surround the vessels like the tentacles of an octopus.

The adventitia of the vessels is more or less continuous with the stroma.

The veins have a perivascular sheath, outside which there is an adventitia of connective tissue.

The *capillaries* of the chorio-capillaris are characterised by their size. Whereas in an ordinary capillary there is hardly room for one red blood corpuscle to pass at a time, here there is room for several (Figs. 40 and 47). They consist of tubes whose walls are formed of endothelial cells. According to Wolfrum their nuclei are never found towards the side of the retina, i.e. not to interfere with their permeability in this direction; but this has been denied.

Schaly describes cells of Rouget (pericytes) around the capillaries. These cells have contractile powers and may help to regulate the blood supply, especially to the fovea where they are particularly numerous.

Towards the retina the capillaries are bounded by the lamina vitrea on either side by connective and elastic tissue continuous with it, and so also towards the outer side. In this tissue endothelial cells but no pigment are found.

The Structure of the Vessels of the Iris.—The vessels of the iris are classically described as having an unusually thick adventitia of almost hyaline appearance. This is only partly true and is the appearance given by stains such as hæmatoxylin and eosin, etc. The adventitia is certainly thick, but if Mallory's connective tissue stain is used a much more accurate idea of the real structure is obtained. The adventitia may be more or less uniform or may be thinner in its inner portion. Most typically, however, the vessel appears to consist of two tubes,

one within the other. The outer is the adventitia proper, staining deep blue, and made up of very fine connective tissue fibres, while the inner consists of the essential blood channel that is the endothelial lining, to which are added, in the case of the arteries, muscle cells and elastic fibres. Between these is a relatively large space (Figs. 41, 42) filled with a gossamer-like tissue to which one would call especial attention. A space of this size in this position is, one thinks, unique, for it is absent in the vessels of the ciliary body and choroid, and so far as one is aware has not been described elsewhere in the body.

FIG. 41.—TRANS. SECTION OF AN ARTERY OF THE IRIS (ZENKER MALLORY'S TRIPLE STAIN.)

To show the two tubes and the space between them.

(*Author's preparation*.)

The space is, in the first instance, no doubt associated with the constant concertina-like movement of the iris in dilatation and constriction of the pupil, and thus with the repeated straightening and wrinkling of the iris vessels.

The outer adventitial coat is continuous with the iris stroma, and as Wolfrum points out is really part of, and therefore anchored to it. Such an arrangement, by which the inner tube is separated from the outer by a space, and where the outer is anchored to the loose tissue of the iris stroma, makes for the greatest freedom of movement of the blood current and the least likelihood of its becoming blocked through kinking.

The arteries and veins are distinguished, not by the thickness of the adventitia which is proportional to the size of the vessels, but by the structure of the inner

FIG. 42.—LONGITUDINAL SECTION OF AN ARTERY OF THE IRIS TO SHOW THE SPACE BETWEEN THE INNER AND OUTER WALLS. ALSO THAT THE ADVENTITIA IS CONTINUOUS WITH THE IRIS STROMA.

tube This is much thicker in the case of the arteries As opposed to a very current view, the arteries are provided with a media consisting of circular muscle fibres (cells) which according to Wolfrum can be followed to the capillaries and elastic fibres in the intima which reach almost as far In the arterial wall proper one recognises three layers of cells (1) the endothelial cells lining the vessel with nuclei whose long axis is that of the vessel itself, (2) the muscle cells with nuclei at right angles to these, and (3) outside these again and lining the space between the inner and outer tubes are pale staining endothelial cells (Fig 42) (In the case of the capillaries Schaly has demonstrated darker staining cells of Rouget alternating with these endothelial cells)

As stated above, the space between the inner and outer tubes is unique in its size and width, but it corresponds in position to the perivascular lymphatic spaces of the retinal vessels and to the Virchow Robin spaces of the cranial vessels These also are lined on their inner side by endothelial cells It seems therefore that the space described above in the iris vessels also probably acts as a lymphatic space

The Nerves of the Ciliary Body

These come from the long and short ciliary nerves which accompany the long ciliary arteries They form a plexus in the ciliary muscle The fibres which are at first medullated lie between the muscle fibres At each bifurcation is a triangular thickening from which innumerable fibrils pass

Sensory fibres are found and recognised by their club shaped endings Vaso motor nerves are also seen They are not medullated and surround the vessels of the ciliary processes

The Nerves of the Iris

The nerves, which are very numerous come from the ciliary plexus Almost all are non myelinated but possess nuclei of Schwann They form various net works There is one in the anterior limiting layer which may be sensory in function Another forms around the vessels A third is seen in front of the dilatator From this plexus the nerve fibrils which emanate are so numerous that each myo-epithelial fibre is thought to receive its own nerve fibre The fibrils terminate at the muscle fibre by end feet which are often endowed with little refractile spherules from which in turn numerous very fine fibrillæ pass (Redslob) There is also a network around the sphincter The nerve fibrils penetrate the sarcoplasm and end in a loop or ring (Roeke)

The innervation of the sphincter seems to be in sectors which explains the vermiform movements of the pupil

The Retina

The retina is the innermost or nervous tunic of the eye It is a thin membrane which in the living is quite transparent and of a purplish red colour, due to the

visual purple of the rods Soon after death, however, the retina becomes white and opaque and the visual purple disappears under the action of light

If a section of the eye be made through the equator, the vitreous removed, and the posterior portion of the retina be examined a small white circular area 1 5 mm in diameter will be seen 3 mm from the posterior pole of the eye This is the optic disc, and is the point where the nerve fibres of the retina pass through the lamina cribrosa to become continuous with the optic nerve, and also the site of entry of the central artery and vein of the retina

A depression is seen in the disc, which varies somewhat in position, size, and depth It is known as the *physiological cup* (Figs 17 93, 157)

It will be noted that normally the nerve head is quite flat[1] and in a plane with the retina It does not form a projection inwards towards the vitreous, and so the name "papilla is a misnomer Briggs, who gave it this name in 1686, was no doubt describing post mortem material in which a swelling of the disc is normally present Such fixatives as Zenker acetic too, may produce a swelling of the disc as an artefact

Another small area of great interest can also be made out practically at the posterior pole It is slightly yellow[2] in colour, hence is called the Macula lutea In the centre of this area is a depression known as the Fovea centralis—the point of most acute vision

If we attempt to separate the retina from the choroid, we find that the retina proper is attached only at two regions, namely, around the optic disc and in front at its dentate termination, the ora serrata, which extends farther forwards on the nasal than on the temporal side and above than below

The pigment layer of the retina remains adherent to the choroid all the way

STRUCTURE

The retina derived from the optic cup is really part of the brain arising as a hollow outgrowth from the fore brain The optic nerve, therefore, is not a true nerve, but a fibre tract connecting as it were one part of the brain with another The outer wall of the cup forms the pigment layer of the retina, the inner wall giving rise to the remainder

This is the reason why disease in the brain so often runs parallel with that of the retina, a good example of this being seen in arteriosclerosis, which so often affects both almost equally

The retina proper consists essentially of the nuclei and processes of three layers of nervous elements placed one on the other, and forming synapses at the so-called molecular zones

They are

1 The visual cells (rods and cones)

[1] See Wolff and Davies, *Brit Journ Ophth* November 1931

[2] See later, p 93

2 The bipolar cells
3 The ganglion cells

The visual cell with its nucleus and process is homologous with a sensory cell in the skin or elsewhere

The nucleus of a bipolar cell corresponds to the posterior root ganglion, its distal process to the peripheral nerve while its central process corresponds

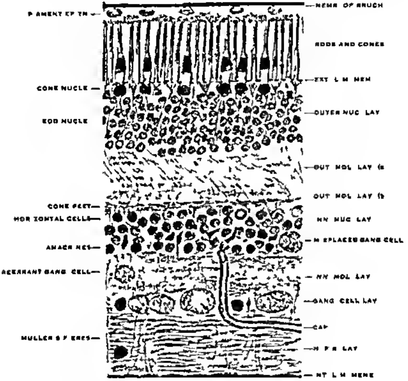


FIG 43—VERTICAL SECTION OF RETINA
(Author's preparation)

to the fibre in the posterior columns of the spinal cord The ganglion cells the first of their kind in the visual path are the homologues of cells in the gracile and cuneate nuclei of Goll and Burdach, the first cerebro spinal cells in the pathway of the sense of touch and sense of position

The whole retina is usually described as having ten layers, which from without inwards are

1 The pigment epithelium
2 The layer of rods and cones
3 The external limiting membrane
4 The outer nuclear layer
5 The outer molecular (plexiform) layer

6. The inner nuclear layer.
7. The inner molecular (plexiform) layer.
8. The ganglion cell layer.
9. The stratum opticum, or nerve fibre layer.
10. The internal limiting membrane.

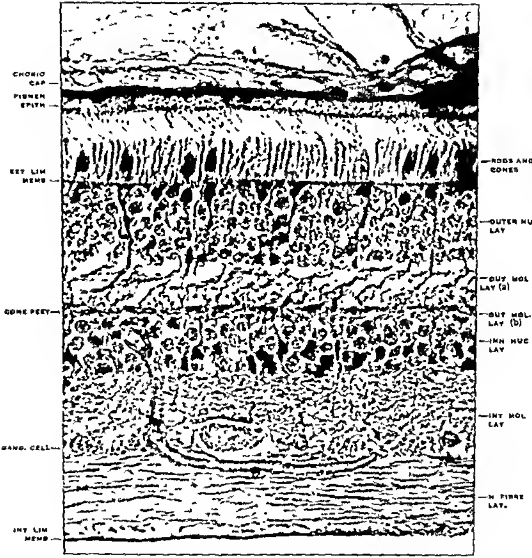


FIG. 43A.—VERTICAL SECTION OF RETINA. (MICRO-PHOTOGRAPH.)

1. **The Pigment Epithelium of the Retina.**—If the eyeball be divided antero-posteriorly and the vitreous and retina removed, the pigment epithelium is seen as a continuous brown sheet extending from the optic nerve to the ora serrata, contrasting markedly in colour with the black of the pars plana of the ciliary body.

In the macular region however, a darker area about the size of the disc is seen

Even under low magnification it is seen that the colour of the pigment epithelium is not uniform there is a fine mottling due to the fact that the cells are not equally pigmented This is responsible for the granular appearance of the fundus as seen with the ophthalmoscope (Salzmann)

With the ophthalmoscope also that is under a magnification of 15 times, often a finer mottling still can be made out due to the pigment in *each* pigment cell

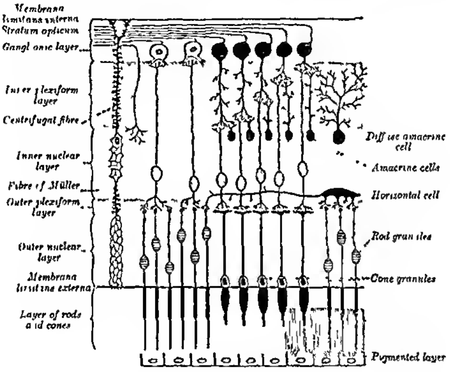


FIG 44—PLAN OF THE RETINAL NEURONES
(From Gray's "Anatomy" after Cajal.)
Note —The cones ought to reach the pigment epithelium

tending to collect at the periphery of the cell leaving the central nuclear portion relatively free (see Fig 45, and p 103)

The pigment epithelium consists of a single layer of cells which is firmly attached to the membrane of Bruch, but only loosely to the rods and cones So in a detachment of the retina, it remains adherent to the choroid with which therefore, it is often described Embryologically, however, it belongs to the retina being developed from the outer portion of the optic cup Viewed from the side each pigment cell is oblong some 12–18 μ long and some 5 μ high Viewed on the flat the cells are placed together like flagstones They are most often six-sided Hence the layer is often referred to as the hexagonal epithelium, but one

finds cells having anything from four to eight sides Also looked at in this way the cell margins appear as clear stripes due to the cement substance between the cells (Fig 45) This cement substance not only separates[1] the cells from each other but also caps the dome of the cell which is the part adherent to the membrane of Bruch It thus comes about that, taken as a whole the cement substance of all

FIG 45 —PIGMENT EPITHELIUM OF THE HUMAN RETINA

(Max Schultze from Quain s *Anatomy* vol 3 pt ii p 49) (*a*) Surface view (*b*) Two cells seen in profile with fine offsets extending inwards (*c*) A cell still in connection with the outer ends of the rods

the pigment cells has the form of a mould used for making bricks This is open towards the rods and cones The bricks themselves are represented by the protoplasm etc of the cells The free edges of the partitions between the various compartments of the mould consist of a denser layer than the remainder and form

FIG 46 —FLAT SECTION OF THE PIGMENT LAYER OF THE RETINA.

Note that the pigment is much denser at the periphery of each cell leaving the central nuclear portion almost free and so appears as a network This pattern can at times be made out with the ophthalmoscope (see p 103)

the membrane which Verhoeff described in 1903 as being homologous to and having the same staining reactions as the external limiting membrane of the retina This membrane, in sections stained with Mallory s phosphotungstic acid hematoxylin is seen as a broken line thickened at the points of junction of the cell boundaries In a flat section it forms a net the holes of which much larger than those of the external limiting membrane are naturally hexagonal and of the same size as the pigment cell (Figs 47 48)

[1] Some hold that the cement substance is deficient at the sides towards the dome and that therefore the pigment epithelial cells form a syncytium

Following Angelucci we may divide each pigment cell into the dome, the base and the pigment processes.

The Dome is the portion towards the choroid. It is almost clear of pigment, contains the nucleus and probably also small droplets of lipoid substances. The nucleus is oval, some 7μ in length, with its long axis parallel to the membrane of Bruch. It is poor in chromatin. The nuclei appear to be of two kinds since some stain blue with Unna's epithelial stain while others stain red (Oguchi).

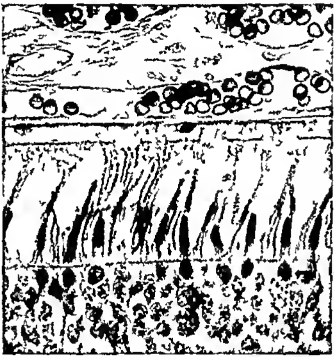


FIG. 47.—VERTICAL SECTION OF THE OUTER PART OF THE RETINA AND INNER PART OF CHOROID. (ZENKER. [illegible] HEM.)

Note that to the right of the figure and in the centre where the membrane of Bruch has become artificially detached from the pigment epithelium its [illegible] nature is clearly seen. Note also Verhoeff's membrane.

([illegible] preparation.)

The Base of the cell contains pigment and from it the processes project like bristles from a brush.

The Pigment Processes lie in the interstices between the rods and cones. Long in some animals, reaching to the external limiting membrane in frogs for instance, the processes are short in the human being, only 5μ in length, and do not extend farther than the junction between the inner and outer portions of the rods and cones. Moreover the contractile properties seen in amphibia have not been definitely proved for mammalia. The pigment called Fuscin by Kuhne is

brown in colour It is present in two forms rounded granules and spindles about 1 5 μ long

The rounded granules are found in the base of the cell The spindles are found in the processes Their elongated form which makes them different from the pigment of the choroid, ciliary body, and iris, immediately stamps any pigment, for instance in pathological processes, as retinal

Fuscin differs from the melanin of the choroid in its greater resistance to heat and chemicals It is however, more easily affected by light which bleaches it in the presence of acid Under the ultra microscope the round granules are deep reddish brown, the spindles, light yellowish brown

FIG 48 —FLAT (ALMOST HORIZONTAL) SECTION OF THE PIGMENT EPITHELIUM OF THE RETINA TO SHOW "VERHOEFF'S MEMBRANE"

At the macula the pigment cells are higher (11–14 μ) and narrower (9–11 μ), hence the darker colour of this region

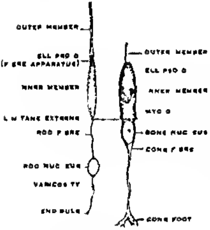
Near the ora serrata exceptionally large cells, some 60 μ in diameter, occur They may have several nuclei Here there are often changes like those which occur in mild choroiditis partly a disappearance, partly a hyperplasia of the pigment epithelium and a fusion of it with the retina (Salzmann)

At the optic nerve the pigment epithelium does not reach quite as far as the membrane of Bruch The terminal cells may be somewhat depigmented or may be heaped up In this case they form the so called "choroidal" ring at the edge of the disc (Fig 93)

2 **The Visual Cells,** i e the rods and cones, constitute the true sensitive part of the retina, the remainder being for the transmission of the impulse Each of these cells may be regarded as a bipolar cell whose peripheral process, corresponding to the sensory ending of a somatic nerve, is either a rod or cone, whose

nucleus is situated in the outer nuclear layer and whose dendrites form synapses with those of the bipolar cells in the outer molecular zone The rods and cones are placed in a palisade like manner on the external limiting membrane, which gives this layer under the low power of the microscope a characteristic finely striated appearance at right angles to the choroid

Each rod whose length varies from 40 μ to 60 μ consists of two segments an outer and an inner The outer is cylindrical highly refractile, and transversely striated and contains the visual purple It is surrounded by a very fine sheath of neurokeratin The outer segment stains with osmic acid, the inner segment takes on nuclear stains It is not unlikely that the transverse striation is a post mortem change or produced by the method of fixation for in the fresh state the contents of the outer segment are entirely homogeneous (Druault) After death or under the action of certain reagents the outer segment fragments into a number of discs corresponding to this transverse striation and may also become bowed Apart from this a longitudinal striation can also be made out This according to Schultze is due to furrows which lodge the processes of the pigment epithelium



I II

Fig 40 —Human Rod (I) and Cone (II)
(After Greeff)

Note —Outer member of cone ought to be longer

The inner segment is slightly thicker than the outer In the fresh state its protoplasm is transparent and homogeneous, but soon after death becomes finely granular

A longitudinal striation seen near the external limiting membrane is due to the fibre baskets of Schultze formed by an extension of this membrane (see below)

Held describes a diplosome near the outer end of the inner member, which sends an *outer thread* through the outer member and an *inner thread* to the external limiting layer

From the inner end of each rod runs a thin varicose *rod fibre* which passes through the external limiting membrane (Figs 40 44) swells out into its densely staining nucleus, the *rod granule* in the outer nuclear layer, and then terminates in a small end knob in the outer molecular layer where dendrites of the bipolar cells arborise round it

According to the latest researches of Balbuena the terminal spherules of the rods are in contact with the cone feet In certain regions where the cones are surrounded by a palisade of rods one sees a bunch of spherules enveloping the cone feet

The Visual Purple is absent in the rods in a zone 3–4 mm wide at the ora

serrata It is also of course missing at the fovea centralis where there are no rods The whole of a retina which has just been removed from an eye kept in the dark will therefore appear purplish red except at these places

The visual purple bleaches rapidly after death

Each cone whose length varies from 85 μ at the fovea to 40 μ at the periphery also consists of two segments Classically the outer segment of the cone is described as conical in shape and much shorter than that of the rod (Fig 50 A and B) but it has however been shown that the outer segment of the cone is much like that of the rod (Fig 43) only it is very much more fragile It does, in fact, reach to the pigment epithelium everywhere in the fundus and not only in the macular region It contains no visual purple The inner portion is bulged and unlike the rod is directly continuous with its nucleus the cone granule staining differently from the rod granule and situated just on the inner side of the external limiting membrane (Figs 43 44) Striation etc is like that of the rods The shape of the cones varies greatly depending on which part of the retina they come from (see Macular Cones)

The stout cone fibre runs from the nucleus to end in the cone *foot* provided with lateral processes which arborise with the dendrites of the bipolar cells in the outer molecular layer

The visual cells with their nuclei and processes are not vascularised but get their nourishment from the chorio-capillaris

According to Osterberg there are 147 300 cones per sq mm at the fovea At the point where the rods commence that is at 130 μ from the centre of the fovea there are 74 800 cones per sq mm 3 mm farther 6 000 cones per sq mm and 10 mm from the fovea about 4 000

The greatest number of rods is found directly under the papilla i e 170 000 per sq mm Towards the ora they get less being from 23 000 to 50 000 per sq mm

The total number of cones is about 7 millions while the rods number about 125 millions

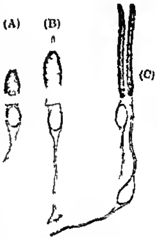


FIG 50 —HUMAN CONES FROM DIFFERENT AREAS OF THE RETINA

A = from near the ora serrata B from midway between ora and disc C from the fovea centralis

(*After Greeff*)

Note The outer member in A and B ought to be longer

Differential Staining of the Rods and Cones—Kolmer who has done most work on the differential staining of the neuro epithelium after stating that he does not believe that there are transition forms between rods and cones writes

By means of certain stains for instance Unna s Orcein polychrome methylene blue tannin stain I succeeded in the human and many animals in colouring the

outer limbs of the cones deep blue, while the rods were entirely uncoloured—which indicates a physico chemical difference between the two

"With Mallory's stain and often with Heidenhain's Azan a distinct difference is seen in the cone and rod nuclei, for the former stain red with Fuchsin, while the latter stain orange

"The above differences can already be made out in cyclostomes, for instance in Petromyzon, as distinctly as in the human

"That the cones are made of different material from the rods I was also able to demonstrate in man and the primates in the following way After fixation in chrome containing fluids and treatment with nascent chlorine, Unna's epithelial stain coloured the inner and outer portions of cones a deep blue (with Wasserblau) while the inner and outer portions of the rods were coloured red (with Safranin)

"Shaffer, indeed, showed as early as 1890 that after fixation by Kulschitsky's fluid and staining in a similar way to Weigert's method for medullated nerve fibres he coloured the cones and cone fibres electively in the human retina

"Also in many fishes the chemical differences between the rods and cones are striking Thus in brosmius—a shellfish like fish—the rods cut easily while the larger cones due to their extremely large albumen content, become so hard with similar fixation that they, like the lens nucleus, jump out of the section during cutting

"It seems to me that the above criteria demonstrated in an extensive range of vertebrates, are quite sufficient to distinguish (with but few exceptions) between rods and cones"

The author has also succeeded in the human in colouring the inner portions of the cones red with Mallory's triple stain after Zenker fixation while the corresponding portion of the rod stained blue This was done both in vertical and in flat sections This method of staining proved especially interesting in the macular region where the inner limbs of the rod like cones stained red (Figs 51 to 53)

In another eye where the sections stained with Mallory's triple stain were inadvertently left washing for a long time the outer elements of the cones stained reddish brown while the corresponding part of the rod stained blue

Spaces between the Outer Limbs of the Rods and Cones.—Schafer in Quain's *Anatomy* writes

"The intervals between the rods and cones are only partially filled by the processes of the hexagonal pigment cells, the remaining part appears to be occupied by a clear substance which, according to Henle and H Muller, is of a soft elastic consistency during life, and in the fresh condition, but soon liquefies after death, but according to Schwalbe is normally liquid"

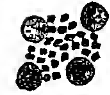
Van der Stricht also found spaces here free from rods and cones in sections stained by silver methods

My own preparations show that these spaces have a definite shape hexagonal

FIG 51

×750

FIG 52



×1500

DIFFERENTIAL STAINING OF RODS AND CONES. (ZENKER. MALLORY'S TRIPLE STAIN)
Cones red, rods blue

FIG 53 — VERTICAL SECTION OF THE OUTER PART OF THE RETINA AND INNER PART OF CHOROID AT THE MACULA (ZENKER MALLORY'S TRIPLE STAIN)

Note that the cones here look like rods but stain like cones The space between the pigment epithelium and the outer part of the cones is an artefact

(Photomicrograph)

FIG 54 — FLAT SECTION OF THE GANGLION LAYER OF THE RETINA × 600

To show the perivascularis gliæ (stained red) P G = perivascularis gliæ P G F = perivascular glia and feet of glial fibres G C = ganglion cell, C T = connective tissue in wall of vessel (stained blue), L = lumen of vessel (Zenker Mallory's triple stain)

(Photomicrograph)

or polygonal in cross sections mirroring as it were the hexagonal pigment cells This would seem to suggest that the rods and cones diverge towards the periphery of the pigment cells and indeed if Max Schultze s figure (Fig 45) be examined with a magnifying glass it will be seen that the rings which represent the cross section of the apices of the rods and cones are largely to be found at the periphery of the cell (similarly in Fig 46) It is possible, however that the spaces although present in all my preparations may be produced as an artefact by clumping

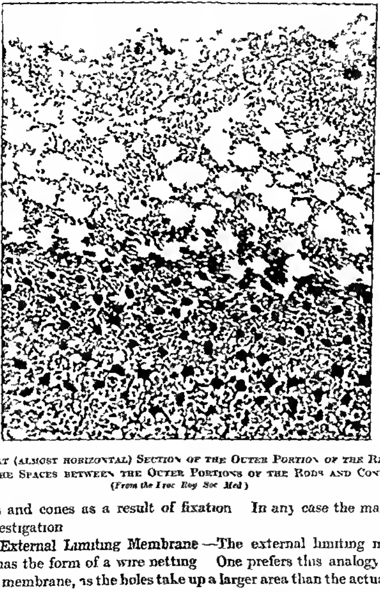


FIG 55—FLAT (ALMOST HORIZONTAL) SECTION OF THE OUTER PORTION OF THE RETINA TO SHOW THE SPACES BETWEEN THE OUTER PORTIONS OF THE RODS AND CONES
(From the Proc Roy Soc Med)

of the rods and cones as a result of fixation In any case the matter requires further investigation

3 **The External Limiting Membrane**—The external limiting membrane of the retina has the form of a wire netting One prefers this analogy to that of a fenestrated membrane, as the holes take up a larger area than the actual membrane itself

Through the holes in the net pass the processes of the rods and cones In a

section at right angles the membrane appears as a series of dots, if the section is slightly oblique, it may appear as a line Its true form can only be appreciated

FIG 56—As FIG 55 SHOWING THE SPACES UNDER HIGHER POWER × 1 500 THE LARGER CIRCLES REPRESENT THE CROSS SECTIONS OF THE CONES THE SMALLER ONES THOSE OF THE RODS

in a flat section parallel to the surface Such a section shows clearly that the diameter of each aperture in the net depends on the structure which passes through it Thus a rod has a small aperture while a cone (Fig 57) has a much larger one

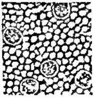


FIG 57—FLAT SECTION OF THE EXTERNAL LIMITING MEMBRANE × 1 000 SHOWING LARGE HOLES FOR CONE FIBRES AND SMALL HOLES FOR ROD FIBRES

(Author's preparation)

In the macular region the holes are all more or less of the same size except at the fovea where the cones are exceptionally fine and the holes correspondingly small At the fovea also the greater length of the cones pushes the external limiting membrane inwards and causes a concavity outwards which is called the fovea externa

FIG 58—FLAT (HORIZONTAL) SECTION OF THE EXTERNAL LIMITING MEMBRANE AT THE MACULA (COMPARE WITH FIG 57) × 1 000

(Author's preparation)

The external limiting membrane is usually described as being formed by the fibres of Müller But, according to Seefelder, the external limiting membrane is already present at the formation of the secondary optic

vesicle when the fibres of Muller have not yet reached this region It seems, therefore, that Lebouecq is probably correct when he states that both the external limiting membrane and the fibre baskets of Oscar Schultze are the remains of the original intercellular cement of the fœtal retinal cells

At the edge of the optic nerve the external limiting membrane may bend round and become continuous with the pigment epithelium, that is, with Verhœff's membrane with which it is homologous, or with the intermediate tissue of Kuhnt [1]

Anteriorly at the ora serrata the external limiting membrane ends at the same level as the pigment epithelium by becoming continuous with the cement substance between the pigmented and non pigmented portions of the ciliary epithelium (Wolfrum)

4 **The Outer Nuclear Layer.**—This consists essentially of the rod and cone granules (nuclei) The rod granule is round, and consists of practically nothing but nucleus with very little protoplasm around it The cone granule is larger, oval, and stains differently As the cone fibres are very short, the granules lie as a single layer situated close to the external limiting membrane (Fig 39)

Occasionally most commonly in the macular region cone nuclei may be found on the outer side of the external limiting membrane (Extruded Nuclei)

The rod and cone fibres continue beyond the granules and end in the outer molecular zone among the dendrites of the bipolar cells The rod fibre ends in a small knob, while the cone fibre terminates in a conical swelling with lateral processes

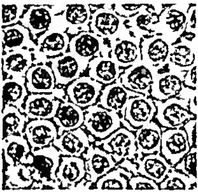


FIG 59 —SECTION OF THE OUTER NUCLEAR LAYER IN THE MACULAR REGION, × 1 000 SHOWING THE CONE NUCLEI WITH THEIR NEUROGLIAL SURROUND NO VESSELS

(Author's preparation)

Generally the granules are about eight deep Directly to the outer side of the disc the layer becomes thinner and then increases again, till it is thickest close to the centre of the fovea centralis At the centre of the fovea it practically disappears (see p 99, and Figs 73, 74 and 75)

5 **The Outer Molecular (Plexiform) Layer.**—This consists essentially of the arborisation of the axones of the rod and cone granules with the dendrites of the bipolar cells

Comprising it also are

(*a*) The processes of the horizontal and amacrine cells

(*b*) The fibres of Muller.

[1] It should be pointed out that embryologically the membrane ought to pass into the glial tissue at the edge of the optic nerve

FIG 60 —FLAT SECTION OF THE OUTER MOLECULAR LAYER × 1 000 (PHOSPHOTUNGSTIC HÆM)

Avascular and much looser in texture than the inner nuclear layer (compare Fig 63)

(In hue a preparation)

The outer molecular layer has a reticular structure, the outer part of which is much looser in texture than the inner (Figs 43 43A)

The denser inner portion is formed for the most part of the horizontal processes of the horizontal and amacrine cells and the lateral processes of the fibres of Müller

As we approach the macular region, however, the reticular structure is lost and the layer takes on a fibrous structure (Figs 74 75, 80) This is due to the fact that the rod and cone fibres, instead of running vertically, become more and more oblique Finally, the fibres from the fovea are almost parallel with the surface Owing to this change in structure the outer molecular layer in the region of the macula has received the name of Henle's fibre layer

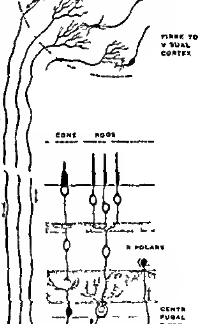


FIG 61 —SCHEME TO SHOW THE COURSE OF THE VISUAL FIBRES FROM THE RODS AND CONES TO THE LATERAL GENICULATE BODY

(Greeff and Cajal modified)

Note that each cone makes connection with one bipolar only

The outer molecular layer, which is thickest at the macula, almost disappears at the fovea

The outer fibre layer is very liable to take up fluid and become swollen on the slightest provocation, both during life and as the result of post-mortem or fixation changes This is especially seen in the central area where the swelling of Henle's fibre layer produces the common post-mortem detachment of the macula This forms a fold the plica centralis, which runs from the outer side of the disc to and including the macula

6 **The Inner Nuclear Layer.**—This consists essentially of the rod and cone bipolar cells

Comprising it also are

(*a*) The horizontal cells
(*b*) The amacrine cells
(*c*) The nuclei of the fibres of Muller
(*d*) Capillaries of the central retinal vessels

The bipolar cells are neurones of the first

order They have their nuclei in the inner nuclear layer and their dendrites arborise in the outer molecular layer with the rod and cone fibres Their axones form synapses with the dendrites of the ganglion cells in the inner molecular zone Except at the macula each bipolar cell collects the impressions of many *rods and cones*

FIG 62 —FLAT SECTION OF THE INNER NUCLEAR LAYER × 1,000

The nuclei of the fibres of Müller stain darker and are more angular than the bipolar nuclei Note the capillary (C) with a deformed blood corpuscle and the neuroglial surround to the cells

(Author's preparation)

The bodies of the bipolar cells resemble the granules of the outer nuclear layer and consist almost entirely of nucleus with very little surrounding protoplasm The whole layer, therefore on ordinary microscopic section resembles the outer nuclear layer but is *generally* much thinner

As we approach the macula this layer gradually becomes thicker and then thins again towards the fovea, where it practically disappears

In the batrachians reptiles and birds one sees a non ramifying fibre coming from the rod bipolar and passing through the external limiting membrane to end between the inner segments of the rods and cones by an enlargement, known as the Mass of Landolt

Quite recently Balbuena discovered a new type of bipolar—the synaxique bipolar The outer end forms a mass directly opposite the cone feet in the external molecular layer These may be the same structures which Fortin compared to little bells and which he thought formed small dioptric apparatuses

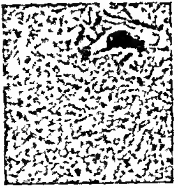


FIG 63 —FLAT (HORIZONTAL) SECTION OF THE INNER MOLECULAR LAYER × 1 000

Vascularised and much denser in structure than the outer molecular layer (compare Fig 40)

(Author's preparation)

The Horizontal Cells are flat cells whose processes spread out horizontally—that is parallel to the surface of the retina They are placed next the outer molecular layer (Figs 44 43)

The Amacrine Cells have a pear-shaped body and a single process which passes inwards and ends in the inner molecular layer Some of them make connection with the centrifugal fibres of the optic nerve They are placed next the inner molecular layer (Figs 43, 44)

Both the horizontal and amacrine cells are probably associational in function

7 **The Inner Molecular (Plexiform) Layer.**—This consists essentially of the arborisation of the axones of the bipolar cells with the dendrites of the ganglion cells Comprising it also are,

(a) The distal processes of the amacrine cells
(b) Fibres of Muller
(c) Branches of the retinal vessels
(d) A few scattered nuclei

The inner molecular zone forms a reticulum which is divided into several substrata by the horizontally coursing processes of the amacrine cells and the dendrites of the stratified ganglion cells (This subdivision into layers is better seen in some animals especially birds than in man)

It has practically the same thickness everywhere in the retina except at the fovea centralis where it is absent

The nuclei present in this layer are those of the endothelium of the vessels (Fig 63) or possibly those of displaced ganglion (Fig 43) or amacrine cells

8 **The Ganglion Cell Layer** —This consists essentially of the ganglion cells of the retina In it are also found

(a) Fibres of Muller
(b) Neuroglia or spider cells
(c) Branches of the retinal vessels

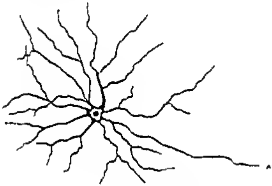


FIG 64—A GANGLION CELL OF THE RETINA
(After Fog I)

The ganglion cells of the retina are multipolar nerve cells which resemble those of the central nervous system They have a clear round or slightly oval nucleus with a well marked nucleolus Nissl granules are well developed (Fig 65) The cells vary greatly in size and shape Generally large they may reach up to 30μ in diameter but may be much smaller especially in the macular region They may be round pyriform or oval

From the rounded inner end of the cell the axis cylinder (Fig 64) comes off and passes into the nerve fibre layer From the opposite extremity (which is usually embedded in the inner molecular layer) one or more dendrites which are thicker than the axis cylinder come off and ramify in the inner molecular layer The processes of the ganglion cells may be *stratified* when they run horizontally in one to three layers or *diffuse* when they branch like a tree and end anywhere in the inner molecular layer

The ganglion cells are neurones of the *second order* and correspond to cells in the *nucleus gracilis* and *cuneatus* Their axones make a cell station in the external geniculate body (Fig 61) In the retina generally the ganglion cells form a single row but on the temporal side of the disc we find two layers As we approach the macula they increase in depth so that up to eight layers may be formed

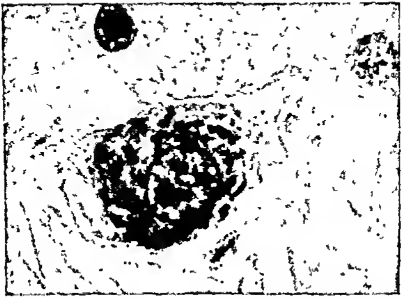


FIG 65.—GANGLION CELL OF RETINA (ZENKER BORELL'S METH BLUE. × 2,000.)
To show Nissl's granules Also note nucleus and nucleolus
(*Author's preparation.*)

at its margin. They decrease again towards the fovea, where they disappear entirely (Figs. 73–75).

Thus, if in any microscopic section we find two or more layers of ganglion cells we know, not only that we are on the temporal side of the disc, but that we are near the macula.

Towards the ora serrata the ganglion cells are sparser and gradually make their way into the nerve fibre layer.

The neuroglia or spider cells have bodies which are smaller than the ganglion cells, and have more densely staining nuclei. They have a large number of fine dendrites.

9. The Stratum Opticum or the Nerve Fibre Layer.—This consists essentially of the axones of the ganglion cells which pass through the lamina cribrosa to become continuous with the optic nerve.

But there are also :

(*a*) Centrifugal fibres.
(*b*) Fibres of Müller (*q v.*).
(*c*) Neuroglial cells.
(*d*) Retinal vessels.

The nerve fibres are arranged in bundles which run parallel to the surface of the retina. (This

FIG 66.—FLAT SECTION OF THE GANGLION CELL LAYER OF THE RETINA (ZENKER PHOSPHOTUNGSTIC ACID. HÆM.)

The large ganglion cell has shrunk somewhat and so shows the glial surround very clearly.

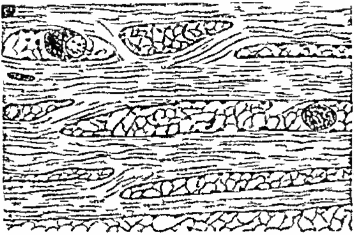


FIG. 67.—FLAT SECTION OF THE NERVE FIBRE LAYER OF THE RETINA
(Author's preparation.)

structure can be made out with ordinary stains and makes it obviously different from that of the molecular layers.)

The bundles anastomose with each other, forming a network in whose meshes are the feet of the fibres of Muller (Fig. 67).

The fibres all converge towards the optic disc. Those from the inner side

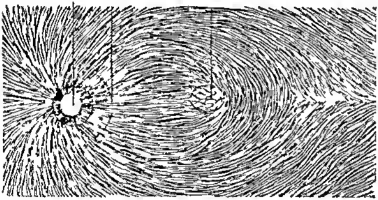


FIG. 68.—THE NERVE FIBRE LAYER OF THE RETINA (SURFACE VIEW OF THE PAPILLO-MACULAR REGION).
(From Poirier, after Dogiel and Greeff.)

reach it without interruption; those from the outer side do not pass through the macula, but have to go round it. The fibres above the horizontal meridian pass above the macula and those below under it.

Thus we find to the outer side of the macula a sort of raphe, from which the nerve fibres arise in a pennate manner (Greeff) (Fig. 68).

Those just to the outer side of the macula encircle this structure closely, while the more lateral ones pass above and below in ever increasing arcs.

The fibres from the macula itself pass straight in towards the outer side of the disc and constitute the important *papillo macular bundle*

The nerve fibre layer is thickest around the margins of the optic nerve, 20–30 μ, and here differs in the different quadrants Thus it is thinnest directly outwards, i e in the region of the papillo macular bundle Next in thickness are the upper and outer quadrant and the lower and outer quadrant, then the innermost part of the edge of the disc and finally the thickest parts are the upper and inner quadrant and the lower and inner quadrant *The relative thickness most probably determines at which part of the disc papillœdema commences The swelling is first visible in the thicker parts, that is, at the upper and inner and lower and inner quadrants next comes the inner edge, then the upper and lower and outer quadrants, while the last part of the disc to show visible swelling will be directly outwards* [1]

From the disc the nerve fibre layer becomes thinner as we pass towards the periphery and near the ora serrata is invaded by the sparse ganglion cells—the two layers becoming one As has been said, it is thinner on the outer side of the disc than in the other quadrants and as we pass towards the macula it becomes thinner still At the bottom of the fovea it seems to disappear entirely, although Dogiel, using methylene blue, showed that even here a fine network of fibres exists

The nerve fibres are non medullated (except when the so called congenital opaque fibres are present) (Fig 158)

They are mostly very fine, but some may reach 3–5 μ in thickness

The Centrifugal Fibres are thicker than the centripetal (Ramon y Cajal) They pass through the ganglion cell layer and inner plexiform layer, and end by ramifying in the inner molecular layer around an amacrine cell or among the elements of the inner nuclear layer (Fig 61)

The Neuroglial or spider cells have an oval nucleus with little protoplasm and numerous fine processes The glial fibres form a kind of membrane (limitans perivascularis of Kruckmann) around the vessels (see p 101 and Figs 72 89)

The retinal vessels are found mainly in the nerve fibre layer, but may also lie in part in the ganglion cell layer (Fig 90)

They do not as a rule project on the inner surface of the retina, but rarely may do so very slightly

The Internal Limiting Membrane.—Between the retina and the vitreous is a membrane[2] which forms both the inner limit of the retina and the outer

[1] See Wolff and Davies, *Brit Journ Ophth* November 1931

[2] According to Redslob (*Traité d'Ophtalmologie* 1939) the membrane has a double contour The outer he holds is formed by the feet of the fibres of Müller and is thus the true internal limiting membrane while the inner is the hyaloid membrane It is quite true that with the denser stains a double contour can often be made out as seen in Fig 69 The inner portion may even separate from the outer and cells may be seen between the two But if we follow this method of description we must always in illustrations label the membrane with both names (which is complicated) and call the membrane which separates the *outer* part of disc from the vitreous the hyaloid since there are *no fibres of Müller here Also the internal limiting membrane will be absent where a large vessel* comes close to the hyaloid (as in Fig 69)

boundary of the vitreous (Figs 43 and 43A) It has, therefore, been called with equal justification the internal limiting membrane of the retina and the hyaloid membrane of the vitreous Here the former term will be used

At the outset it must be emphasised that the membrane stains like collagenous tissue Thus with Mallory's triple stain it is coloured blue

In an ordinary section of the retina this membrane appears as a thin line some 1-2 mm thick perfectly smooth towards the vitreous but having marked

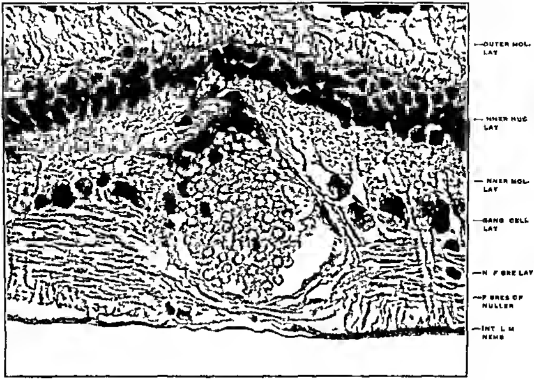


Fig 49—Vertical Section of the Inner Portion of the Retina (Zenker Verhoeff's Elastic Stain)

Note the thinning of the internal limiting membrane where the vessel lies close to it No fibres of Müller (well seen to the right of the section) come to it in this region

(From O S L K 1937)

irregularities towards the retina The exact significance of these irregularities has not been decided They may either be the foot pieces of the fibres of Muller themselves (Salzmann) or the material which binds these to the membrane proper

In a flat section of the retina the membrane appears in two parts (*a*) a homogeneous portion and (*b*) a curious and rather characteristic mosaic which seems to be due to the irregularities on the retinal aspect Sometimes on the surface of

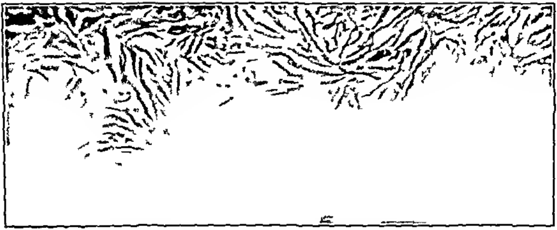


FIG. 70.—FLAT SECTION OF THE INTERNAL LIMITING MEMBRANE.
The inner portion is homogeneous (glass-like); the outer shows the characteristic mosaic.
(*Trans. O.S.U.K.* 1937.)

this mosaic (or lying loose where the membrane has become detached as an artefact, which happens quite frequently, especially *in paraffin sections*) (Figs. 71, 90), one sees a honeycomb of fibres forming no doubt the material which binds the foot pieces of the fibres of Muller together (see Van der Stricht).

A very interesting and instructive picture is often seen if one examines a section of the retina where a large vessel comes close to the membrane. Here, opposite the vessel, the membrane is very thin. *It is smooth both on its retinal and vitreous aspects and no fibres of Muller go to it* (Fig. 69).

Further, when it is remembered that the fibres of Muller stain red with Mallory's triple stain, as does neuroglia, it becomes clear that the membrane which is labelled the internal limiting membrane in all or nearly all modern textbooks of anatomy cannot be formed by the apposition of the bases of the fibres of Muller as is usually and classically described (see also Salzmann and Kolmer). The feet of the fibres of Muller are in fact only attached to this membrane.

The internal limiting membrane is a typical glass-like (hyaloid) membrane. It is present at the fovea but is gradually lost at the nerve head where it is continuous with the neuroglia forming the central connective tissue meniscus of Kuhnt (Fig. 159).

FIG. 71.—TO SHOW THE NETWORK OF (RED STAINING) FIBRES LYING ON A DETACHED (BLUE STAINING) INTERNAL LIMITING MEMBRANE. (FLAT SECTION. ZENKER. MALLORY'S TRIPLE STAIN.)
(*Trans. O.S.U.K.* 193 .)

The Retinal Neuroglia

Apart from the actual nervous elements the retina like all parts of the central nervous system contains glial elements which act as its connective and supporting tissues The glia forms a sheath to each nervous element and thus serves to insulate the various neurones from each other (Figs 59 60) Perhaps also it has a trophic function

The newer methods of staining have taught us that in the retina as well as in the central nervous system there are different types of glial cells

There are (1) the fibres of Muller (2) Golgi s spider cells (3) astrocytes (4) horizontal bands of glial tissue alone or associated with the smaller vessels (5) the microglia

1 **The Supporting Fibres of Muller**—The fibres of Muller are long narrow

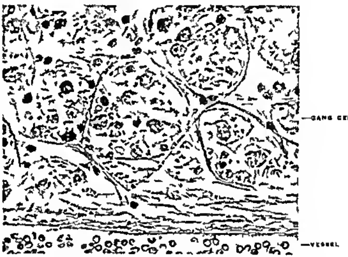


Fig [illegible]—Flat Section of the Ganglion Cell Layer of the Retina to show the Horizontal Bands of Glial Fibres

The glial feet ending on the vessel wall can be made out but are not very clearly demonstrated

very complicated structures which pass through the whole thickness of the retina from the internal to the external limiting membranes

The nucleus is situated at the level of the inner nuclear layer It can be distinguished from the rounded bipolar nuclei among which it lies by its elongated angular form (Figs 43, 43A) and its staining reactions Thus with Mallory s phosphotungstic acid hæmatoxylin it stains much darker than the nuclei of the bipolar cells (Fig 62)

The nucleus of Muller s fibre is bipolar in character It sends a radial process internally and one externally

Both the nucleus and the processes send branches laterally which may be in the form of lamellæ or fibrillæ

The lamellæ occur in the region of the inner and outer nuclear layers and

neighbouring lamellæ unite to form a honeycomb in the alveoli of which the cellular elements are contained (Figs 62, 66)

Numerous short branches are also given off to the plexiform layers

As the inner process passes through the ganglion cell and nerve fibre layers, it gives off no lateral branches or only a few and thus can be seen here without any special stain

At the level of the inner molecular layer the inner process bifurcates or divides into several branches which are attached to the internal limiting membrane by a hollow base or foot It is usually stated that the bases or foot pieces, of adjoining fibres are united by their edges to form the internal limiting membrane of the retina This view is denied by both Salzmann and Kolmer (see also p 87)

Traced externally the outer process reaches the external limiting membrane Some hold that it forms this membrane and is then continued on as fine fibrillæ which invest the base of the rods and cones and are called the fibre baskets of Oscar Schultze According to Lebouecq however, this view is not tenable (see p 79)

Bielschowsky preparations show the diplosome of the fibres of Müller to be directly beneath the limitans externa

Near the fovea the fibres of Müller instead of running at right angles to the layers of the retina become oblique following though not exactly the slope of the clivus

2 **The Golgi spider cells** are small glial cells with a round or oval nucleus and numerous cytoplasmic processes similar to those found in the grey and white matter of the central nervous system They are most numerous near the papilla, in the inner plexiform, ganglion cell, and nerve fibre layers

3 **Astrocytes or star cells** are found here and there in the ganglion cell layer They are most numerous in the papilla and optic nerve

4 **Horizontal Bands.**—One also often finds well developed bundles of glial fibres in the nerve fibre and inner plexiform layers either alone (Fig 72) or accompanying the precapillary and capillary vessels

5 **The Microglia** (del Rio Hortega's *third* [1] glial element) —The cell body is most often triangular but may be round oval or rod shaped It may have one or many processes Hortega believes the microglia to be derived from mesoderm and not from ectoderm They constitute wandering cells which are phagocytic and hence act as scavengers especially to fatty granules, in pathological processes It has also been suggested that the microglia belongs to the reticulo endothelial system

[1] Rio del Hortega divides the neuroglia into three kinds

1 *The Macroglia or Fibroglia* —This consists of the fibrillary and protoplasmic astrocytes to which class the fibres of Müller belong

2 *The Oligodendroglia* is constituted by cells poor in dendrites They usually occur in association with myelinated fibres but may be found in the ganglion cell layer

3 *The Microglia*

The Retinal Neuroglia

Apart from the actual nervous elements the retina like all parts of the central nervous system, contains glial elements which act as its connective and supporting tissues The glia forms a sheath to each nervous element and thus serves to insulate the various neurones from each other (Figs 59 66) Perhaps also it has a trophic function

The newer methods of staining have taught us that in the retina as well as in the central nervous system there are different types of glial cells

There are (1) the fibres of Muller (2) Golgi s spider cells (3) astrocytes (4) horizontal bands of glial tissue alone or associated with the smaller vessels (5) the microglia

1 **The Supporting Fibres of Muller** —The fibres of Muller are long narrow

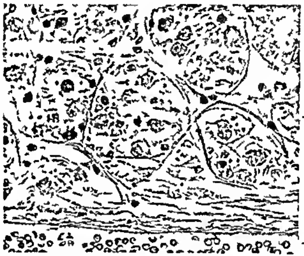


Fig 7[illegible] —Flat Section of the Ganglion Cell Layer of the Retina to show the Horizontal Bands of Glial Fibres

The glial fibres ending on the vessel wall can be made out but are not very clearly demonstrated

very complicated structures which pass through the whole thickness of the retina from the internal to the external limiting membranes

The nucleus is situated at the level of the inner nuclear layer It can be distinguished from the rounded bipolar nuclei among which it lies by its elongated angular form (Figs 43 43A) and its staining reactions Thus with Mallory s phosphotungstic acid hæmatoxylin it stains much darker than the nuclei of the bipolar cells (Fig 62)

The nucleus of Muller's fibre is bipolar in character It sends a radial process internally and one externally

Both the nucleus and the processes send branches laterally which may be in the form of lamellæ or fibrillæ

The lamellæ occur in the region of the inner and outer nuclear layers and

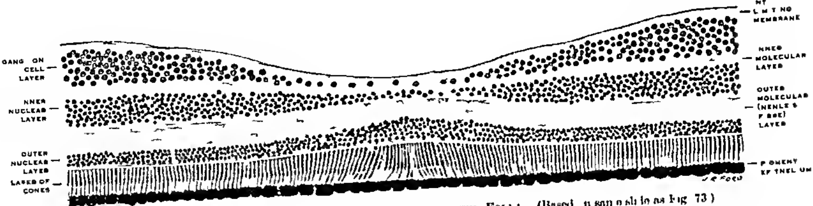


FIG 74 —SECTION THROUGH THE MACULA NEAR THE CENTRE OF THE FOVEA (Based on same slide as Fig 73)

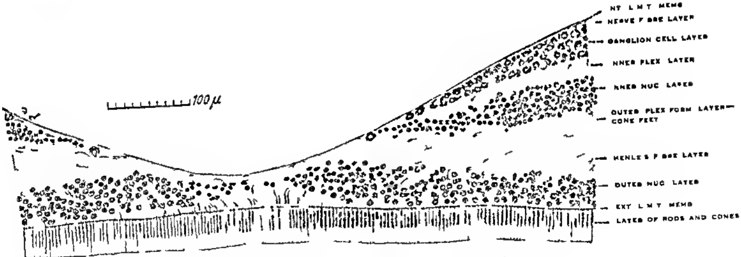


FIG 75 —SECTION THROUGH THE CENTRE OF THE FOVEA CENTRALIS
Note that here the outer nuclear layer is also reduced to a few scattered cells
(From F sler n the k rz s Ha d o k d r Ophtha olog e)

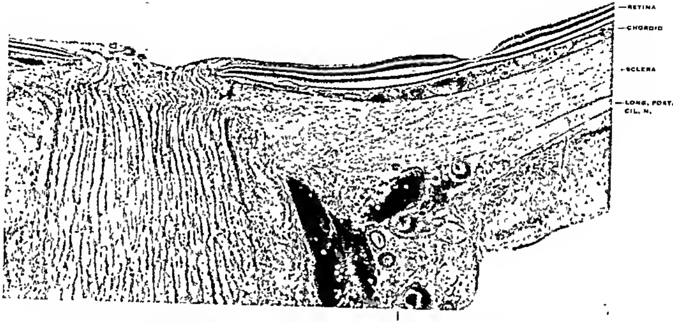


FIG. 76.—ANTERO-POSTERIOR (HORIZONTAL) SECTION OF THE OPTIC NERVE AND MACULA, PASSING THROUGH THE FOVEA CENTRALIS. (ZENKER. WEIGERT'S HÆM. AND PONCEAU S.)
Note the increased thickness of the choroid at the macula and especially at the fovea.
(Author's preparation.)

Also the inner and outer molecular and inner nuclear layers are gradually reduced to thin membranes The outer nuclear layer, just next the fovea (some hold *at* the fovea), actually increases in thickness but at the fovea itself is reduced to a single layer (see Figs 74 and 75)

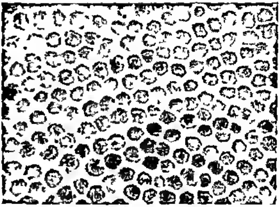


FIG 77 —THE CONE MOSAIC AT THE MACULA FLAT SECTION THROUGH THE INNER PORTIONS OF THE MACULAR CONES × 1 000

There are no rods at the fovea only cones (Fig 77) and these are much more slender and longer than elsewhere with the result that they form an elevation which encroaches on the other layers

It will thus be seen that at the fovea centralis the layers of the retina are spread aside, so that light may fall directly on the true percipient elements, namely the cones

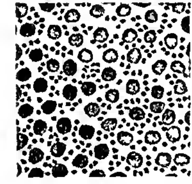


FIG 78 —FLAT SECTION THROUGH THE INNER LIMBS OF THE RODS AND CONES IN THE MACULAR REGION CLOSE TO THE ROD FREE AREA × 1 000 ONLY A FEW RODS TO EACH CONE

(Author's preparation)

At the fovea centralis each cone is connected to only one ganglion cell Its impulse is therefore much purer, and the image received by the brain much sharper than elsewhere in the retina, being as it were insulated from the impulses of neighbouring cells It is these facts that make the fovea the point of most acute vision In the retina generally each visual cell is in relation with many (up to 100) *ganglion cells*

The pigment layer is thickened, and so is the chorio capillaris

The increased choroidal blood supply is due to the fact that the macula has no retinal blood vessels

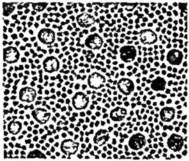


FIG 79 —FLAT SECTION THROUGH THE INNER LIMBS OF THE RODS (SMALLER) AND CONES (LARGER) NEAR THE MACULA

Note that the cross section of the rods is not circular × 1 000

The external limiting membrane is sometimes pushed inward, forming a depression which faces the choroid and has been called the *fovea externa*

The yellow colour of the macula lutea is best seen in post mortem eyes in which the retina has already become clouded It is not seen in perfectly fresh eyes nor ordinarily with the ophthalmoscope (But it can be made out with red free light (Vogt)

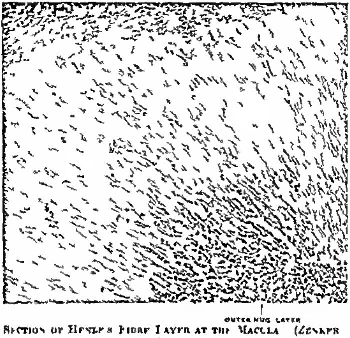


FIG 80 —FLAT SECTION OF HENLE'S FIBRE LAYER AT THE MACULA (ZENKER PHOSPHOTUNG HÆM)

Note the difference between the inner and outer portions The outer portion has the structure of fibrous tissue the inner forms a net (See also Fig 81) Note also the columns of cone nuclei invading the fibre layer

(Author's preparation)

and in darkly pigmented fundi if daylight is used for illumination (Dimmer [1])

The reason for this is that the transparent yellow colour is seen with a brown background in the excised eye and a red background with the ophthalmoscope

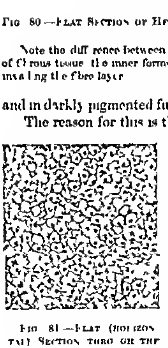


FIG 81 —FLAT (HORIZONTAL) SECTION THROUGH THE INNER (LESSER) PORTION OF THE OUTER (HENLE'S) FIBRE LAYER AT THE MACULA × 1000

(Author's preparation)

Chevallereau and Pollack [2] showed that if one detaches the retina of an eye immediately after enucleation spreads it on a slide and then looks at it with a white background the yellow colour can be seen

Gullstrand [3] however believes the yellow colour is a post mortem phenomenon for on detaching a fresh retina and shaking with physiological salt solution he found it quite colourless

[1] Die macula lutea der menschlichen Netz Haut' von Graefe's *Archiv* Bd 65 p 486 (1907)

[2] Chevallereau and Pollack *Annales d'ocul* vol 138 p 241 (1907)

[3] Gullstrand von Graefe's *Archiv* Bd 67 p 1 (190)

(c) **The Ora serrata** —The ora serrata is the dentate fringe which marks the termination of the retina proper It is some 8 5 mm from the limbus about 6 mm from the equator and 25 mm from the optic nerve The teeth of the ora serrata are best marked where the ciliary body is narrowest i e on the nasal side and particularly in the upper nasal quadrant (Fig 28) On the temporal side they often fail completely and the border is often finely and irregularly wavy and angular The teeth correspond in position to the intervals between the ciliary processes and all the irregularities of the development in the corona ciliaris are reflected in the ora serrata (Salzmann) Towards the ora serrata the rods and cones become shorter and thicker but continue to the limit of the retina It is curious therefore as Salzmann points out that the extreme periphery of the retina is blind

The nuclear layers become thinner and eventually fuse

The ganglion cells become sparser invade the nerve fibre layer and both end 0 5 1 mm from the ora serrata

There is a great increase in the neuroglial supporting tissues

The external limiting membrane is continued between the two layers of

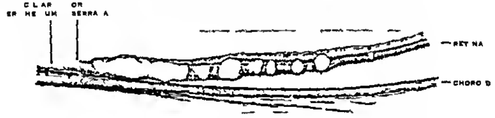


Fig 8 —The Retina at the Ora Serrata, showing Cystic Degeneration (From Salzmann)

ciliary epithelium The internal limiting membrane becomes thinner and is doubtfully continued over the ciliary epithelium

At the ora serrata all the essential elements of the retina cease so that beyond this point (and indeed slightly posterior to it) it does not give rise to the sensation of vision The retina is in fact continued forward over the inner aspect of the *ciliary body as two layers of cells an outer cuboidal and pigmented an inner* columnar and non pigmented This portion is called the pars ciliaris retinae

Similarly the prolongation of these two layers of cells behind the iris is called the pars iridica retinae The most anterior portion of the optic cup forms the fringe of pigment round the margin of the pupil (Fig 34) which can be seen with the naked eye especially when the pupil is small

Peripheral Cystoid Degeneration

(Iwanoff's Retinal Œdema Blessig's Cysts)

Cystic spaces are not infrequently found in the retina at or close to the ora serrata They may be regarded as physiological and although best marked in

the old they may be found in quite young people They usually commence in the outer molecular layer and gradually increase in size till they fill the whole space between the inner and outer limiting membranes Cystic degeneration is much more marked on the temporal side where the teeth of the ora serrata are small than on the nasal where they are best developed (Fig 28)

It has been suggested that the bursting of one of these cysts may induce a detachment of the retina which so commonly starts at the ora serrata and most often in the lower temporal quadrant

Their origin is probably associated with the relatively poor blood supply of the region, and their formation may be regarded as an atrophic phenomenon

The Blood Supply of the Retina

The retina gets its main blood supply from the arteria centralis retinæ but its outer portion namely, the rods and cones and the outer nuclear layer, is avas

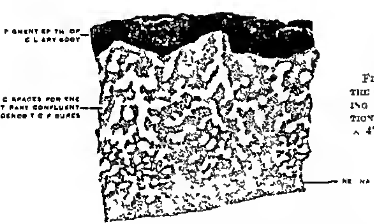


Fig 83 —Retina of the Ora Serrata showing Cystic Degeneration Surface View × 4"

(From Salzmann)

cular and nourished by the chorio capillaris, which exists in fact for this purpose The outer molecular layer, also for the most part avascular, is fed partly from the choroidal partly from the retinal vessels (See also cilio retinal artery and other branches from circle of Zinn p 99)

The double vascular supply of the retina brings it into line with the double supply to the brain namely a cortical and a basal system of vessels which do not anastomose The choroid may be regarded as the forward continuation of the pia arachnoid

The Arteria Centralis Retinæ —The central artery of the retina is a slender vessel some 0 28 mm in diameter (Henle) which comes off the ophthalmic close to the optic foramen usually in company with one or other branch most commonly the medial ciliary trunk (Quain) It runs a wavy course forward below the optic nerve outside but adherent to the dural sheath to some

10–15 mm behind the eye Here, at a point on the under and inner aspect[1] of the nerve, it bends upwards to pierce the dura and arachnoid, from both of which it receives a covering

Having reached the subarachnoid space clothed by the above membranes, it bends forwards and also to one or other side[2] After a very short course,[3] it again bends upwards at nearly a right angle and passes through or rather invaginates the pia to reach the centre of the nerve The entering vessel is thus clothed by the whole thickness of the pia (and at first by some subarachnoid trabeculæ as well), and takes with it the contained (pial) vessels It is also surrounded by a *sympathetic nerve plexus* (Krause) *which is called the* nerve of Tiedemann

At the centre of the nerve the artery bends forwards, and then in company with its vein which lies on its temporal side, it passes anteriorly to the lamina cribrosa which it pierces to appear inside the eye *It lies quite superficial in the* nerve head not being covered by nerve fibres but only by that layer of glia (the connective tissue meniscus of Kuhnt), which closes the physiological cup on the side of the vitreous (Fig 159) It climbs up the *inner* side of the cup and at about this point divides into two branches (superior and inferior) which, bending at a right angle or nearly so, pass into the retina (Fig 93)

It will thus be seen that from the point on the under and inner aspect of the nerve where the artery lies outside the dura to and including its bifurcation, it makes five bends (Fig 176)

Branches.—(1) Some of the branches referred to as *Group A* (p 261)

(2) The central collateral arteries (arteriæ collaterales centralis retinæ) (see p 262)

(3) Terminal branches

The superior and inferior branches of the arteria centralis subdivide into nasal and temporal branches of which the nasal are usually the smaller This second division usually takes place about the margin of the disc but may occur in the nerve in which case four branches appear on the disc

The retinal vessels divide dichotomously, as they proceed towards the ora serrata, where they end in capillaries *which do not anastomose with any other system of vessels*

From the arteries in the nerve fibre layer twigs are given off which pass into

[1] There has been much argument as to which aspect the artery pierces All are agreed that it is the under side, but some hold with Vossius that it is the under and outer aspect This author says that the fœtal cleft in the optic nerve rotates through 90° during fœtal life Leber (in *Graefe Saemisch*) points out that there is no foundation for this, and agrees with Deyl that it is the under and inner aspect

[2] This is probably the reason why one has never been able to get an antero posterior section which shows the artery passing through the membranes and in the nerve

[3] That this portion does exist is shown by the fact that a transverse section of the nerve and its sheaths cuts the artery transversely

the ganglion layer, and capillaries from them pass just to the outer side of the inner nuclear layer but no farther, the retina to the outer side of this point being avascular (Figs 43 90)

The macular region is supplied by twigs from the superior and inferior temporal vessels but the fovea itself is entirely free of all blood vessels

The small vessels which run radially from the superior and inferior macular

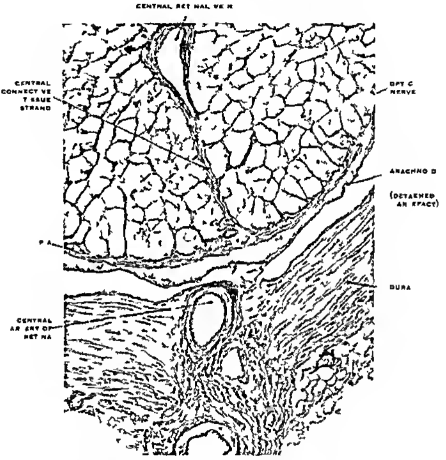


FIG 84 —CENTRAL ARTERY PASSING THROUGH DURA THE VEIN IS IN THE NERVE
([illegible]'s preparation)

vessels form (according to Leber) capillary loops which leave an avascular zone from 0 4 to 0 5 mm at the fovea The superior and inferior macular branches supply the perifoveal capillaries almost equally so that a horizontal raphe exists through the fovea *which according to Roenne accounts for the horizontal division of the fixation area frequently seen in obstruction of an arterial branch*

The arteria centralis may be regarded as an end artery, for if it is blocked

blindness results It does however send a few twigs to Zinn or Haller's scleral circle

The Circle of Zinn or Haller (circulus arteriosus nervi optici) is formed by a circular anastomosis between two four or more short ciliary arteries which have pierced the sclera for the most part on the medial and lateral sides of the optic nerve The ring of vessels so formed lies in the sclera close to the nerve (Fig 176)

From it numerous branches pass forwards to the choroid inwards to the optic nerve and backwards to the pial network

The branches which pass inwards invade the lamina cribrosa and also send branches to the nerve head and neighbouring retina

These last branches are usually very small and only supply a very small area

FIG 85 —THE CENTRAL VESSELS OF THE RETINA ARE IN THE SUBARACHNOID SPACE

(*Author's preparation. From Wolff and Davies "Brit Journ Ophth.," 1931*)

of retina but they may be larger—anything up to a cilio retinal artery which is not uncommon

A cilio-retinal artery can be seen with the ophthalmoscope as a vessel with a hook shaped origin running from just within the outer edge of the disc towards the macula and supplying this area

There is a capillary anastomosis (but no more than that) between the branches of the circle of Zinn and those of the arteria centralis in the region of the lamina cribrosa and nerve head (see p 269)

A cilio retinal vein is rare

The Retinal Veins follow the course of the arteries more or less A vein may run parallel to the corresponding artery for a short distance (Fig 93) but

here and there a vein will cross the artery either superficially or deeply or may be at some distance from it. The diameter of the artery is, as a rule, about two-thirds to three-quarters that of the vein with which it runs, and this applies to the arteria and vena centralis also. The retinal veins do not anastomose, but near the ora serrata their terminal twigs bend round, run circularly parallel to the periphery of the retina, and form an incomplete ring. The most peripheral retinal vessels are capillary arches, but even these do not reach the ora, so that an avascular zone is present here. The arteries end farther back than the veins. The formation of the vena centralis from the superior and inferior retinal veins takes place at about the level of the lamina cribrosa (Fig. 93), i.e. somewhat proximal to the division of the artery into its primary branches, which occurs in the retinal portion of the optic nerve.

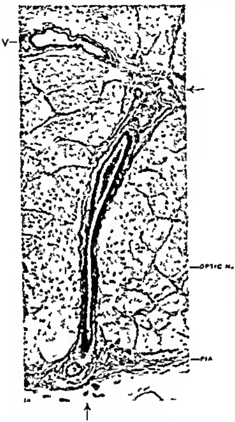


FIG. 86.—TRANSVERSE SECTION OF THE OPTIC NERVE.

To show the central artery passing into the centre of the nerve along a radius of its cross section. V = the central retinal vein which is diverging from the artery to a different point on the periphery. The arrows point to the central collateral vessels.

(*Author's preparation.*)

The vena centralis lies on the temporal side of the artery in the nerve and leaves it somewhat proximally. The artery and vein may cross the subarachnoid space together, but more often they part company at right angles to each other (Fig. 86) in the nerve and reach its periphery at different points. The vein always has a longer course in the subarachnoid space and pierces the dura farther from the globe than the artery.

It most commonly opens directly into the cavernous sinus, after having given a branch to the superior ophthalmic vein, but may drain into the latter vein entirely. Very rarely it opens into the inferior ophthalmic veins.

It is the anastomosis with the orbital veins (as shown by Sesemann) which negatives *von Graefe's theory that papillœdema is produced by pressure on the cavernous sinus.*

The diameter of the central artery is about 200 μ, that of the vein about 225 μ.

Structure.—In structure the central retinal artery in the optic nerve resembles that of a medium sized vessel (Parsons)[1]

The Intima—The artery is lined by a layer of *endothelium* whose nuclei, placed so that their long axis is that of the vessel, project into the lumen of the vessel Beneath this is a *subendothelial* or intermediate layer, which is not present at birth but develops with increasing age

It consists of connective tissue which stains homogeneously with hæmatoxylin or van Gieson but shows circularly arranged fine elastic fibres with Weigert's elective stain

Outside this is the usual (Henle's) elastic fenestrated membrane (membrana elastica interna)

The Middle Coat or Media consists of circularly arranged unstriped muscle fibres with rod like nuclei having their axis at right angles to the length of the vessel There is a *very little* white fibrous connective tissue and some elastic fibres

The Outer Coat or Adventitia—Directly next the muscle fibres is an indefinite *membrana elastica externa*, which fades off into the *adventitia* proper This consists of connective tissue with many elastic fibres arranged in circular and longitudinal bundles Externally it passes gradually into the connective tissue sheath

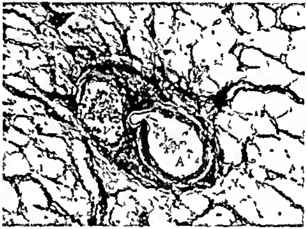


Fig 87—Transverse Section of the Central Vessels just behind the Lamina Cribrosa

To show that the arteria centralis *does* give off a branch (marked by an arrow) in this region a fact denied by a number of authors This vessel followed anteriorly in serial sections was found to break up into branches which *passed into the lamina cribrosa*

(*Author's preparation*)

The Vein has an endothelial lining, a thin subendothelial layer, a media with very few muscle cells but many elastic fibres, and a thin adventitia with fine fibres but little elastic tissue There is neither membrana elastica interna nor externa

After division into its branches the walls of the retinal arteries get much thinner, and in the nerve fibre layer the walls especially the muscularis, are but little developed The muscle, however, can be followed to the finer branches

The adventitia is sharply demarcated from the surrounding nerve tissue, which is bounded by a kind of border membrane formed by glia (limitans perivascularis of Kruckmann) (Figs 54, 89)

Between the glia (derived from ectoderm and the adventitia derived from

[1] See Parsons' *Pathology of the Eye*, vol ii, p 659

mesoderm) there is a potential space which becomes apparent in atrophic conditions of the retina resulting from obliteration of the vessels and in such conditions as retinitis pigmentosa becomes filled with pigment

The Retinal Capillaries are arranged in an inner and an outer plexus The inner plexus lies in the nerve fibre layer

The outer plexus which communicates only slightly with the inner, reaches to the outer side of the inner nuclear layer

Each capillary according to *Kruckmann*[1] has three distinct layers surrounding it

There is (1) the endothelial lining containing Rouget cells (Schaly 1926)[2]

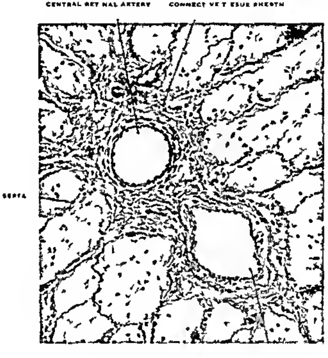


FIG 88—THE RETINAL VESSELS IN THE CENTRE OF THE OPTIC NERVE
(*Author's preparation*)

Around this is (2) a membrane continuous with the adventitia of the larger vessels and lastly (3) comes the limitans perivascularis formed by the glia Between (1) and (2) is the perivascular lymph space containing loose connective tissue and a few endothelial cells (His)

[1] Krückmann von Graefe's *Archiv* Bd 60 pp 3 0 and 45? (190) *ibid* *Zeit f Augen* xxxv i 1 (1917)

[2] Schaly *Thesis* Gröninger 19 6

The Lymphatics of the Retina.—There are no true lymphatic vessels. The lymph, however, circulates between the various elements of the retina, and in the perivascular sheaths, and, following the veins, is carried through the lamina cribrosa into the lymphatic spaces of the optic nerve.[1]

THE APPEARANCE OF THE FUNDUS AS SEEN BY THE OPHTHALMOSCOPE

The fundus, or back of the eye, appears red, owing partly to the blood of the choroid, partly to the pigment epithelium The colour is lighter in fair people, darker in dark people, depending on the amount of pigment in the pigment epithelium and in the choroid

If there is much pigment in the pigment epithelium the choroid is hidden

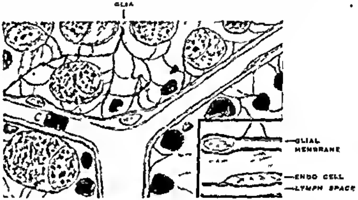


FIG 89—FLAT (HORIZONTAL) SECTION THROUGH THE GANGLION CELL LAYER OF THE RETINA

Note the structure of the capillary and the glial fibres *Inset* semi schematic enlarged view of section of capillary (Phosphotung Hæm) C = deformed red-blood corpuscle in capillary

(*Author's preparation*)

altogether, and the fundus appears a uniform brownish red. In extreme cases, as in the dark races, the fundus is almost dark grey.

The fundus has a finely granular appearance, due to the fact that the pigment epithelium varies in thickness and thus is not equally dark all over. A finer mottling is also often seen since the pigment tends to collect at the periphery of each pigment epithelial cell[2] (Fig 45).

[1] According to Schieck, the lymphatics of the retina run with the central retinal vessels and open into the subarachnoid space *Levinsohn, on the other hand, believes that they pass out through the dura with these vessels*

[2] "*The pigment of the retinal pigment epithelium (when viewed on the flat) tends to collect* towards the periphery of the cell, leaving the central nuclear portion relatively free of pigment. It is probable that the darker the fundus the more the central portion is invaded In not too highly pigmented fundi, therefore, the pigment forms a network, the individual holes of which are constituted by a single living epithelial cell Now the diameter of a hexagonal cell is about 16 μ, this multiplied by 15, which is the magnification given by the direct method of ophthalmoscopy, makes 240 μ, i e about 0 25 mm

If we take into consideration the shrinkage produced by the preparation of a microscopic section, I think we shall not be far wrong if we make this figure 0 3 mm or 1/75 in, which is well within the *visual limits I have seen this network quite often, and so have my colleagues to whom I have spoken about it I believe it can be made out best in fair fundi, in the macular region*"—Wolff, Eugene, *P R S Med*, 1938, p 1104

If the pigment in the pigment epithelium is less marked, and that of the choroid profuse, a tessellated fundus is produced. This consists of dark areas surrounded by red apparently anastomosing (see p. 61) bands, produced by the choroidal vessels, for the most part the veins. These bands are not sharply defined as they are to a certain extent obscured by the pigment.

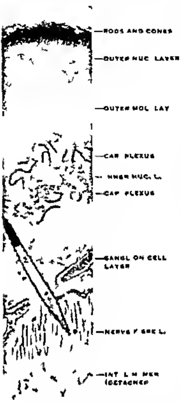


FIG. 110.—FLAT (ALMOST HORIZONTAL) SECTION OF THE RETINA TO SHOW ITS VASCULARISATION. (ZENKER. MALLORY'S TRIPLE STAIN.)

Note.—The main vessels lie in the nerve fibre and ganglion cell layers. The capillary plexus in the ganglion cell layer is not visible here (see Fig. 91), but the plexuses at the inner and outer parts of the inner nuclear layer are well shown.

The less pigment there is in the pigment epithelium and the choroid the more the sclera shows through and the fairer will be the fundus.

In very fair people, and more so in albinos, in whom there is little or no pigment, the choroidal vessels can be seen distinctly. The vessels are broader and less sharply defined than the retinal vessels which run superficial to them. Moreover, they appear flat and ribbon like, and show no light reflex. Also, unlike the retinal vessels which branch dendritically and do not anastomose, the choroidal vessels *appear* to form a dense network (see p. 61), except anteriorly, where the *straight* vessels pass towards the ora serrata.

The Optic Disc is pink owing to the numerous[1] capillaries which it contains (Fig. 159). It must be emphasised, as it is curiously often forgotten, that the white element in its colour is due to the *lamina cribrosa*, and not to the nerve fibres of the "papilla" which are of course non medullated.[2]

The optic disc under normal conditions lies in the same plane as the retina, and does not therefore form a projection as the name "papilla" would lead one to suppose (Fuchs, Testut, and others[3]).

The optic disc is excavated by a funnel shaped depression, called the physiological cup, which varies much in form and size. It is most often not in the centre of the disc but displaced slightly to the temporal side. It tends to be absent in high hypermetropia. Its colour is whiter than the rest of the disc, because there are fewer vessels and nerve fibres obscuring the lamina cribrosa. Very often

[1] When these disappear, as in optic atrophy, the disc appears white.

[2] The nerve fibres can be seen, however, in the normal fundus if red free light be used as the source of illumination.

[3] See also Wolff and Davies, *Brit. Journ. Ophth.*, 1931.

the holes in this membrane for the passage of the nerve fibres can be seen as grey dots. *They become more evident in glaucoma and atrophy of the disc.*

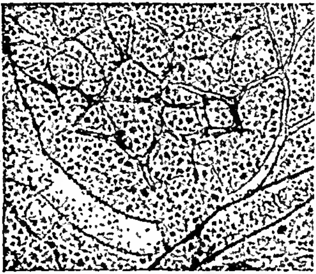


FIG 91.—FLAT SECTION OF THE GANGLION CELL LAYER AT THE MACULA TO SHOW THE CAPILLARY PLEXUS.

The optic disc is pinker in colour to the inner side of the physiological cup than to the outer. This is due to the greater thickness of nerve fibres and more capil-

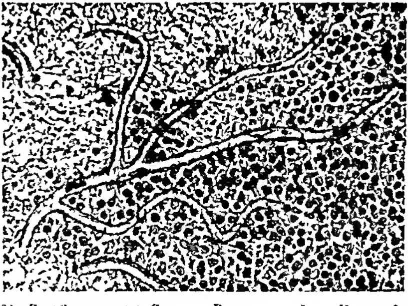


FIG 92.—FLAT SECTION OF THE CAPILLARY PLEXUS IN THE INNER NUCLEAR LAYER.
(Author's preparation.)

lary vessels For the same reason the inner edge of the disc tends to be less well defined than the outer

The Retinal Vessels climb up the inner side of the physiological cup The arteries are easily distinguished from the veins The arteries are narrower of a brighter red colour and have a well marked light streak or reflex along their middle The light streak along the veins is much less marked It is the image of the source of light used in the ophthalmoscopic examination

When the scleral canal is straight the end of the arteria centralis is seen in optical section and the branches appear to come off at 180°

If the intra mural portion of the optic nerve is directed outwards as well as forwards (temporally oblique scleral canal) the nasal border of the physiological cup is steep or overhanging The arteria centralis is usually invisible and its first divisions make an angle which is open towards the temporal side

If the scleral canal runs forwards and inwards (nasally oblique canal) the artery can be seen for some distance and the central vessels appear displaced towards the temporal side

It should be noted carefully that normally the light streak is not lost as the vessels pass over the edge of the disc With the slightest amount of swelling of the disc (as in papillœdema) the vessels bend over its edge and the image of the source of light is thrown beyond the pupil It thus does not reach the examining eye and the bent portion of the vessel appears dark In this way we get the loss of light reflex so important in the diagnosis of papillœdema

Pulsation in the veins is physiological In the arteries it is pathological and occurs especially in *glaucoma* (or when the tension of the eye is artificially raised by pressing on it with the finger) and in *aortic regurgitation*, but is also found in anæmia when syncope is imminent and in exophthalmic goitre

The *connective tissue* or *scleral ring* is the white ring or part of a ring seen often next the disc This may be due to the border tissue not covered by the epithelium or to the side wall of an oblique scleral canal

The Choroidal Ring is a dark ring (or portion of a ring) outside the scleral ring It is produced by a heaping up of pigment epithelium, hence choroidal is a misnomer (Elschnig)

The Macula appears as a small oval area devoid of vessels of a deeper red than the rest of the fundus and often slightly stippled with pigment

The retinal reflexes which usually change their position with the slightest movement of the eye or ophthalmoscope are fixed in the macular region

The oval macular reflex comes from the wall which surrounds the macula The fovea forms a small concave mirror, and so produces the bright foveal reflex (which at times may be so bright as to deserve the name of bull's eye lantern reflex)

The region of the clivus is however darker than the surrounding retina because light falling on it from the ophthalmoscope is not reflected back through the pupil, also the retina here is very thin and the pigment epithelium much denser

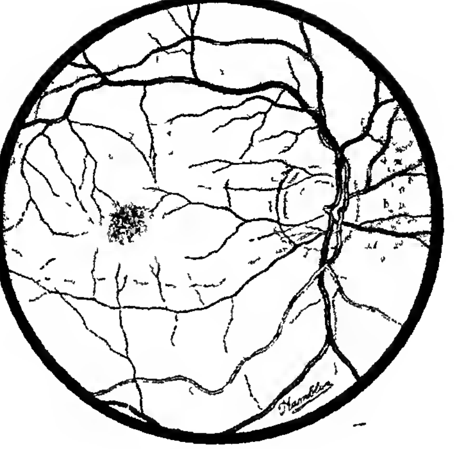


Fig. 93.—The Normal Fundus.

(Direct image of the right eye.)

The central vessels climb up the inner side of the physiological cup. The central artery appears as a single stem which is just visible here and then divides into two branches which appear to separate at an angle of 180°. (Often the stem is invisible where the scleral canal is quite straight forward, or it may be seen for some distance in a very oblique canal; more rarely it appears as two or more trunks.)

The central vein, on the other hand, appears as two trunks, since its formation (seen hazily) is in the lamina cribrosa. It is lateral to the artery.

As the vessels pass over the edge of the disc they do not lose their light streak.

The macula is seen as an area darker red than the rest of the fundus. Its centre (the fovea), seen as a whitish reflex, lies below the centre of the disc.

At the edge of the disc are a pigmented (choroidal) crescent and a scleral ring.

The normal striation which is often seen above and below the disc and due to the *non medullated* nerve fibres has come out much too prominently in the figure.

The Anterior and Posterior Chambers

The space in front of the lens and suspensory ligament is divided into two by the iris (Fig 17)

In front of the iris is the anterior chamber, behind it the posterior chamber

The Anterior Chamber is bounded in front by the cornea and a small portion of the sclera

The amount of sclera entering into the formation of the anterior chamber is about 2 mm above, 1 5 mm below, and 1 mm at the sides [1]

Behind is the iris, a part of the ciliary body, and that portion of the lens which presents through the pupil

At the periphery of the anterior chamber is its so called *angle*, and it is here that we find the sponge work of the ligamentum pectinatum iridis, with the spaces of Fontana which drain into the canal of Schlemm (see p 39, and Fig 23) The anterior chamber is about 3 mm deep at its centre and is narrowest not at the angle but slightly medial to this (Fig 23)

The Posterior Chamber is somewhat triangular on section, the apex of the triangle being where the edge of the iris rests on the lens The base is formed by the ciliary processes and the valleys between them, in which are the recesses of Kuhnt.

The posterior wall is formed by the lens and suspensory ligament and the anterior by the iris

Both anterior and posterior chambers are filled with aqueous humour, which consists essentially of 98 1 per cent of water, with a trace of sodium chloride and albumen Its exact composition is found on p 116

The Lens

The lens [2] of the eye is a transparent elastic bi convex body of crystalline appearance placed between the iris and the vitreous

The diameter of the lens is 9–10 mm , its thickness, from 4 to 5 mm , varies greatly as the eye is focused for distant or near objects

Like all lenses, that of the eye presents for examination two surfaces, anterior and posterior, and a border where these surfaces meet, known as the equator (æquator lentis)

The anterior surface, less convex than the posterior, is the segment of a sphere whose radius is 9 mm

It is in relation in front, through the pupil with the anterior chamber of the eye, with the *posterior surface of the iris*, the pupillary margin of which rests on the anterior surface, with the posterior chamber of the eye, and with the ciliary processes.

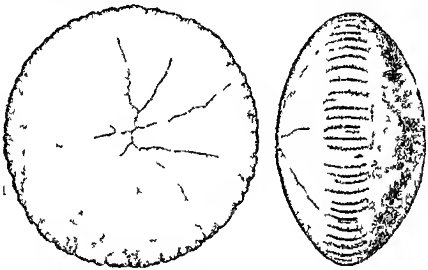
[1] Rochon Duvigneaud measuring from the limbus to the angle finds 2 25 mm , 2 mm , and 1 25 mm , while Lagrange finds (from limbus to a point opposite the attachment of the iris) 1 75 mm , 1 45 mm , and 1 mm as the corresponding figures

[2] *It forms by far the most striking feature when the eyeball is opened so no wonder the ancients made it the seat of vision instead of the retina*

The centre of the anterior surface is known as the anterior *pole* and is about 3 mm from the back of the cornea

The posterior surface more curved than the anterior forms the segment of a sphere whose radius is 6 mm It is usually described as lying in a fossa lined by the hyaloid membrane[1] on the front of the vitreous but it is separated from this by a slight space filled probably with aqueous humour This post lenticular space was described long ago by Berger and appeared to be confirmed by the slit lamp (see p 171)

The Equator of the lens forms a circle lying 0 5 mm within the ciliary pro



From behind From the side

FIG 94—THE LENS

Note that the equator is not smooth

(From Eisler)

cesses It is also in relation with the zonule of Zinn and the canal of Petit The equator is not smooth but shows a number of dentations corresponding to the zonular fibres (Fig 94) These tend to disappear during accommodation when the zonular fibres are loose

Structure of the Lens

The lens consists of

1 Its capsule
2 The anterior epithelium
3 The cement substance or amorphous material
4 The lens fibres

The Capsule of the lens forms a transparent structureless highly elastic envelope

[1] It is now held to be exceedingly doubtful whether a hyaloid membrane exists (see p 114)

When cut or ruptured its edges roll out and then curl up so that the outer surface is innermost It is much thicker in front than behind and the anterior

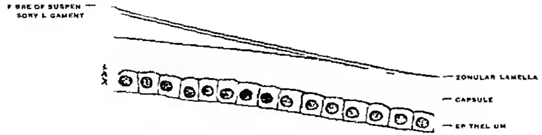


FIG 95 —LENS CAPSULE AND ZONULAR LAMELLA

and posterior portions are thicker laterally, just within the attachment of the zonular fibres than at the poles It is this difference in the thickness of the central and lateral parts of the anterior capsule which Fincham believes is responsible for the hyperbolic form of the anterior surface of the lens during accommodation

A lamination of the capsule has been described and seems to be confirmed by the fact that the zonular or anterior lamina may be separated from the remainder pathologically

The Anterior Epithelium (Figs 95 96 19) —This consists of a single layer of cubical cells spread over the front of the lens deep to the capsule There is no corresponding posterior epithelium since the posterior cells were used up in filling the central cavity of the lens vesicle

If we trace the cells of the anterior epithelium towards the equator we find that they gradually become columnar and elongating are eventually converted into lens fibres In Fig 96 all the stages of development of the lens fibres can be seen

It will be noted that the base of the cell i e the part in contact with the capsule becomes the posterior part of the lens fibre while the opposite end grows into the anterior portion of the

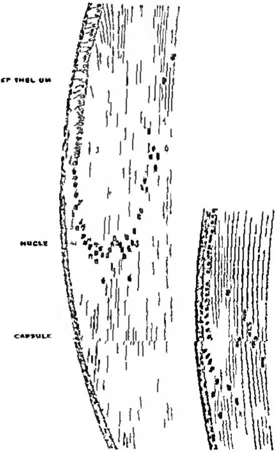


FIG 96 —MERIDIONAL SECTION OF THE EQUATORIAL REGION OF THE LENS
I New born II Old man
(From Poirier after Otto Becker)

lens fibre The nuclei form a somewhat S shaped nuclear zone at the equator (see also p 300)

The Cement Substance or Amorphous Material—The various elements forming the lens are bound together by an amorphous substance[1] which glues the various fibres to each other and is found in the following positions

(a) Beneath the capsule both in front and behind (Testut)

(b) A thin layer just deep to the anterior epithelium (Schwalbe) This probably represents the debris of cells in the embryonic lens vesicle (Fig 235)

(c) The central strand

The central strand occupies the axis of the lens running from the anterior to the posterior pole Then jutting out from this axial collection towards the equator we find three shelves of amorphous material which divide the lens into sectors

Looking at these shelves end on in the fœtus or infant we find that they form a Y the arms of which are separated by angles of 120° The anterior Y is vertical the posterior Y inverted which is the contrary of the classical anatomical description

These figures are known as the anterior and posterior lens stars or sutures

In the adult towards the anterior and posterior surfaces the rays are much more complicated there being six or more primary and many subsidiary ones but in front and behind the embryonic nucleus the original Ys persist throughout life (see slit lamp picture Fig 116)

It is into these shelves of amorphous material that the ends of the lens fibres are inserted

The Lens Fibres—Each lens fibre is a long prismatic six sided band consisting of an albuminoid material enclosed in a pseudo membrane—pseudo, because it consists of the same material as its contents only is more dense

The first lens fibres were formed from the posterior epithelium and ran from the back to the front of the vesicle But the later ones are derived from the equatorial portion of the anterior epithelium

Here as we have seen we find all stages in the formation of a lens fibre from its cell (Fig 96)

The newest lens fibres are laid on externally to the older deeper ones and so the lens acquires a laminated structure On equatorial section the laminæ are cut transversely, forming the radial lamellæ of Rabl (Fig 97) while antero *posterior section shows them as long fibres placed one on the other in concentric* layers The fibres belonging to each lamina are of the same length

The superficial (youngest) fibres too are nucleated their nuclei lying near the equator and arranged so as to form a letter S in meridional section Moreover their sides are quite smooth

The deeper older fibres lose their nuclei become less succulent as it were and their edges become serrated the serrations of one fitting into those of its neigh

[1] It is not visible in ordinary sections and it must be emphasised that anything but a minimal amount of this material must be taken as a post mortem or pathological change

bour Although some of the first formed lens fibres go from pole to pole of the later ones none do

In the infantile lens each starts and finishes on the anterior and posterior Ys respectively in such a way that the nearer the axis of the lens it commences the farther away it ends (Fig 195)

The fibres formed later, for instance the superficial ones of the adult lens, start and finish on the more complicated stellate figures conforming, however, to the above rule

Two of the sides of the hexagonal lens fibres are longer than the remainder, and adhere much less firmly to the neighbouring fibres than do the short sides It follows that if we treat the infantile lens with alcohol which dissolves the cement substance it will first of all divide into three sectors, and then each of these will separate into laminæ like the layers of an onion

New lens fibres are laid on throughout life, and as the central portion which corresponds to the keratin layer of the skin cannot be shed, the lens keeps on growing This, however, is not proportional to the number of fibres, for the older ones, as we have seen shrink According to Priestley Smith the lens at the 65th year is one third larger than at 25

The consistency of the lens varies, the more superficial portion or *cortex* being softer than the central part or *nucleus* The nucleus increases with age The lens becomes flatter with age, but its refractive power is retained by an increase in the refractive index of the nucleus

In early cataract the nucleus becomes too sclerosed and the eye often becomes myopic

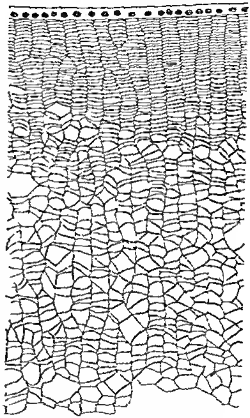


FIG 97 — PERIPHERAL PORTION OF AN EQUATORIAL SECTION OF THE HUMAN LENS TO SHOW THE RADIAL LAMELLÆ (*From Rabl*)

The colour of the lens, too changes with age In the infant and young adult it is quite colourless After about thirty five years the central portion gets a yellow tinge which becomes darker and more extensive as time goes on In the old man the lens often has an amber colour

One other point of practical importance must be mentioned In old people the lens often appears grey when viewed by indirect illumination *This appearance may easily be mistaken for a cataract by the uninitiated*

The Suspensory Apparatus of the Lens

The Zonule of Zinn consists of series of delicate homogeneous transparent fibrils which run from the inner surface of the ciliary body to the equatorial zone of the lens

Their exact origin and indeed their exact nature are still a matter of dispute

They used to be regarded as being split off from the hyaloid membrane at the ora serrata and Salzmann (1912) describes some of the fibrils as arising from the vitreous

Some hold that they are secreted by and are attached to the ciliary epithelium or the internal limiting membrane, others that they are simply a modification of the vitreous

The most posterior fibrils come from the ora serrata, the most anterior from the heads of the ciliary processes The majority, however, arise from a slight ridge known as *the posterior zonular border*, which lies 1 5 mm in front of and imitates the indentations of the ora serrata

The fibrils are closely attached to the pars plana and to the elevations of the ciliary processes, so that if separated from these some pigment will remain adherent on the zonula

In the valleys between the ridges the zonule forms folds and lies loose It is into these folds, or recesses of the posterior chamber, as Kuhnt called them, that "the ciliary glands" were held to open

The fibres are classified as

1 Orbiculo posterior capsular fibres—from the pars plana to the posterior lens capsule.

2 Orbiculo anterior capsular fibres—from the pars plana to the anterior lens capsule

3 and 4 Cilio posterior capsular fibres and cilio anterior capsular fibres—from the corona ciliaris to the posterior and anterior lens capsule respectively

From the apices of the ciliary processes the zonular fibres pass to the capsule of the lens It is to this free portion that the name *suspensory ligament* of the lens is applied

The majority of the fibres pass forwards to be attached to the capsule just anterior to the equator and some go backwards to be attached behind it

A few probably go to the equator itself, but this is disputed Of the fibres which are attached behind the equator some arise from the pars plana while others pass backwards from the corona ciliaris The latter, the orbiculo ciliary fibres, cross the former and are attached farther back on the lens

Between the anterior and posterior fibres is a space, triangular on cross section, known as the canal of Petit [1]

[1] Although the above is now the usual description Petit himself thought that the hyaloid membrane split at the ciliary body the anterior portion forming the suspensory ligament the posterior continuing over the front of the vitreous and that he had injected the space between the two It was Hannover who actually showed that one could inject the space between the anterior and posterior portions of the suspensory ligament

This communicates with the posterior chamber by means of the slit like spaces between the fibres of the zonule and also with the post lenticular space of Berger

The zonule of Zinn as a whole forms a ring somewhat triangular on meridional section It fixes the lens and enables the ciliary muscle to act on it In accommodation the zonular fibres are slackened there is less tension on the capsule of the lens which therefore becomes more convex

With removal of the iris when viewed from in front or the vitreous when looked at from the back the individual bundles of fibrils can be seen passing from the ciliary body to the lens (Fig 28) This can be made out with the naked eye but better with a loupe and better in the fixed than in the fresh specimen

The fibrils on the zonule can also be seen with the slit lamp in cases of congenital dislocation of the lens or absence of the iris (see p 171)

The Vitreous

The vitreous humour is a transparent colourless gelatinous mass which fills the posterior[1] four fifths of the globe Its shape is that of the cavity in which it lies Thus it has the form of a sphere which is indented anteriorly to form the fossa patellaris which lodges the lens At the sides it supports the ciliary body (covered by the zonule) and the retina Through its central region runs the hyaloid canal which in the fœtus lodges the hyaloid artery

The vitreous lies in contact but is not adherent to the retina It is however attached to the optic disc and more especially to the ciliary epithelium in a zone 1 5 mm broad immediately adjacent to the ora serrata This area is known as the base (Salzmann) or origin (Wolfrum) of the vitreous for it is here that as the result of fixation or hardening fluids or under pathological conditions the vitreous remains adherent Even severe injuries do not tear the living vitreous from this situation and when it does give way it takes part of the ciliary epithelium with it (Salzmann)

Also some fibres pass from the front of the vitreous to the capsule of the lens (Wieger s ligamentum hyaloidea capsularе)

These are however very weak and easily torn i e they do not prevent the lens from being removed with its capsule

The hyaloid canal (canal of Cloquet or Stilling) starts in front of the papilla as a funnel shaped area (area Martegiani) passes through the vitreous as a narrow canal 1 2 mm wide and expands again anteriorly in the fossa patellaris of the lens It is probable that in the adult the canal does not run a direct sagittal course as is usually depicted It probably sinks with gravity and moves about with movements of the eye and head It must also be mentioned that its very existence has been denied Its walls are formed of a condensation of the vitreous and not by an actual membrane (Ida C Mann)

[1] Not the posterior chamber

The Hyaloid Membrane

It used to be and still is taught that the vitreous is surrounded by a thin structureless membrane

From the ora serrata to the optic disc it is said to be applied to the innermost layer of the retina, the membrana limitans interna Instead of covering the optic disc the hyaloid membrane is reflected at its edge to form the walls of the canal of Cloquet Behind the lens the walls of the canal separate to form a cup shaped hollow in which the lens lies (patellar fossa)

At the ora serrata the zonule is held to split off from the hyaloid membrane which then becomes exceedingly thin posterior to the suspensory ligament of the lens It seems however, that anteriorly there certainly is no hyaloid membrane although a condensation of the vitreous can be made out in microscopic sections (Fig 29), while posteriorly also the internal limiting membrane forms both the inner limit of the retina and the outer boundary of the vitreous

It is therefore becoming more and more generally held although the controversy is by no means ended, that the hyaloid membrane, apart from the internal limiting membrane of the retina (*q v*) is an artefact

The Structure of the Vitreous

The vitreous used to be described as consisting of a fine reticular framework in whose meshes are a gelatinous fluid and certain cells called the vitreous corpuscles

These cells are of many various shapes Some are round with one or more nuclei, others are branched terminating sometimes in a varicose, tendril like structure, others again are characterised by a large vacuole The corpuscles, which are for the most part possessors of amœboid movement, are found most frequently near the ora serrata and optic disc

The work with the ultra microscope of Baurmann 1923–6, Comberg 1924 Heesh 1926 Redslob 1927–32 and Duke Elder[1] 1929 tends to show that the vitreous is a gel [But while many of its qualities are those of a gel the difference between the central and peripheral portions the changes with age the firm attachment at its origin or base and certain pathological considerations such as the definite arrangement of the blood corpuscles in certain hæmorrhages into the vitreous make it clear that this cannot be the whole explanation of its structure]

Macroscopically the vitreous has the appearance of a colourless transparent jelly

Microscopically absolutely fresh vitreous has no structure at all

With the ultra microscope perfectly fresh vitreous is optically empty Soon however fibrillæ of colloidal dimensions such as are seen in soap gels appear When the vitreous has been standing for some time the fibrillæ break up into separate particles

[1] See Duke Elder *Brit Journ Ophth* , Monograph Supplement IV Also Redslob 1932

Thus the appearances seen with various fixatives are artefacts The vitreous has no structure in the ordinary sense of the word

The appearance seen with the slit lamp is due to the fact that the fibrillæ become evident when large numbers of them are arranged in a direction perpendicular to the incident light as obtains near the surface of the vitreous

The optical effect of this arrangement is that of a waved or moire appearance suggestive of marcelled hair or watered silk

Where the arrangement of the fibrillæ is haphazard the vitreous appears optically empty

A similar appearance is seen when any gel of like constitution is examined by the slit lamp in a glass vessel which is gently shaken

This appearance it must be remembered is an optical illusion for the fibrillæ are far too small being somewhat of the size of molecules to be seen with the slit lamp

The vitreous humour consists of 98 5 per cent of water with traces of albumen NaCl etc Its exact composition is seen in the table on p 116

It has in fact practically the same composition as the aqueous except that it contains in addition a small amount of muco protein and a substance the exact nature of which has not been determined but which is necessary for the setting of the vitreous in a gel (Duke Elder)

It has also almost the same specific gravity refractive index conductivity and osmotic pressure as the aqueous The apparently great difference between the two humours thus depends on the presence of two constituents which absorbing water and swelling up in solution give the entire mass properties of increased viscosity, elasticity and a certain amount of solidity Such a state in contradiction to the dispersed nature of a sol (the aqueous is a very dilute sol) is called a ' gel '

It is probable that the above two extra constituents of the vitreous humour are secreted by the (retinal) ectoderm The fluid part of the vitreous is dialysed from the capillaries of the ciliary region (as is the aqueous) A physical combination of these produces the turgescent gel which forms the vitreous body (Duke Elder) (see above however)

The Lymphatic Drainage of the Eye

The aqueous humour must be regarded as the lymph of the eye although its composition is not that of lymph in the body generally it contains less albumen and does not clot unless pathologically altered

There are three main theories with regard to the formation of the aqueous

(a) That it is a *filtrate* from the ciliary vessels

(b) That it is *secreted* by the so called ciliary glands

(c) That it is a dialysate through the endothelium of the capillaries of the ciliary body (Duke Elder)

However formed, the aqueous passes from the ciliary body into the recesses of the posterior chamber and thence anteriorly or posteriorly.

Anterior Drainage.—From the recesses the aqueous flows[1] into the posterior chamber, then through the pupil into the anterior chamber. From here it may pass at the angle through the spaces of Fontana into the canal of Schlemm, and thence to the anterior ciliary veins. Another way open to it is via the crypts of Fuchs (where we remember the anterior epithelium and anterior border layer are wanting) directly into the iris. From here the flow is partly into the ciliary veins, partly into the supra-choroidal lymphatic space. From the latter the drainage is via the perivascular lymphatics around the venæ vorticosæ through the sclera to Tenon's space.

Posterior Drainage.—From the posterior chamber again the lymph passes backwards through the slit-like spaces of the suspensory ligament into the canal of Petit, around the equator of the lens. From here it passes into the post-lental space of Berger and then down the hyaloid canal to the perineural lymphatics of the optic nerve.

A table from Duke-Elder's *Textbook of Ophthalmology* is appended for reference. It shows the composition of the aqueous, vitreous and serum. Note that the aqueous is much more like the cerebro-spinal fluid than the lymph or serum.

THE GENERAL CHEMICAL COMPOSITION OF THE INTRA-OCULAR FLUIDS OF THE HORSE (DUKE-ELDER, 1931)

Quantities in gms. per 100 c.c.

	Aqueous	*Vitreous*	*Serum*
Water	99.6921	98.6813	93.3738
Solids dried at 100° C.	1.0869	1.108[illegible]	0.5362
Total protein	0.0[illegible]01	0.066[illegible]	7.3692
Albumen	0.0078	0.0077	[illegible].9557
Globulin	0.0123	0.0115	4.4135
Mucoprotein	—	0.0211	—
Residual protein	—	0.0250	—
Fibrinogen	traces	traces	+
Immune bodies	traces	traces	+
Ferments	traces	traces	+
Fats	0.004	0.007	0.13
Cholesterol	traces ?	0.0005	present
Non-protein N	0.0236	0.0261	0.0239
Total N	0.0269	0.0301	—
Urea	0.028	0.0[illegible]9	0.027
Amino acids	0.029	0.030	0.035
Creatinine	0.002	0.001	0.002
Organic acids	traces	traces	—
Sugar	0.0953	0.0973	0.0910

[1] The actual flow must be minimal and has even been denied.

	Aqueous	Vitreous	Serum
Sodium	0.2787	0.2731	0.3351
Potassium	0.0189	0.0192	0.0201
Calcium	0.0062	0.0068	0.0101
Magnesium	0.0026	0.0020	0.0028
Chlorine	0.4371	0.4168	0.3664
Inorg P (P_2O_5)	0.0033	0.0031	0.0030
Inorg S (SO_4)	0.0061	0.0062	0.0058
Ammonia	0.003	—	Mestrezat and Magitot (1921)
Lactic acid	0.02	—	Wittgenstein and Gaedertz (1926)
Oxygen	20–40 mm	—	de Haan (1922) Mawas and
	70 vols. %	—	Vincent (1926)
Total CO_2	71 vols %	—	Takahashi (1926)
	60 70 vols %	—	Kronfeld (1927)
	47.5 vols %	43.7 vols %	58.1 vols % (Saht, 1930)

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CHAPTER III

THE APPENDAGES OF THE EYE

THESE comprise the eyelids, the eyebrows, the conjunctiva, and the lacrimal apparatus

THE EYELIDS

The eyelids are movable folds which act as curtains protecting the eye from injury or excessive light They also aid the pupil in regulating the amount of light which reaches the retina Only when they are shut can the visual cortex really be at rest

The upper eyelid extends above to the eyebrow, which separates it from the forehead—the lower passes usually without line of demarcation into the skin of the cheek Often, however, especially in the old, two furrows, the naso jugal and malar folds, occur just beyond the orbital margin, and limit it below

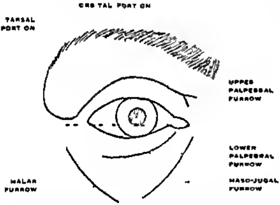


FIG 98—THE SURFACE ANATOMY OF THE EYELIDS (L W)

At the furrows the skin is tied to the periosteum (on the inner side, at the naso jugal fold, the band of fascia passes to the interval between the orbicularis oculi and the quadratus labii superioris) The furrows mark the line of junction between the loose tissues of the lid and the denser tissues of the cheek, and because the skin is tied down tend to limit effusions, and, especially in the old, fat which has escaped from the orbit

The upper eyelid is much the more movable of the two, being supplied by a special elevator muscle (levator palpebræ superioris) When the eyes are open and looking straight ahead, it just covers the upper part of the cornea, when they are closed it covers the whole The lower lid, on the other hand, is just free of the cornea when the eye is open and rises only slightly when it shuts (see also table on p 122)

When the eye is open an elliptical space, the palpebral fissure, remains between the lid margins, which meet in the inner and outer "angles" or canthi of the eye

The outer angle is acute It measures about 60° when the eye is widely open,

and about 30–40° normally The outer angle is often continuous with a groove which passes outwards and downwards from it that is a continuation of the line of the margin of the upper eyelid It is around this groove that the furrows of the goo e s foot are placed The external canthus is some 5 7 mm from the orbital margin and about 1 cm from the fronto malar suture

The inner angle —The lower boundary is horizontal while the upper passes downwards and inwards—as do therefore the corresponding canaliculi The inner angle is continued inwards by the *ridge* produced by the medial palpebral ligament

The outer angle is placed directly against the globe The inner more rounded is separated from it by a little bay—the tear lake (lacus lacrimalis) In this is a yellowish elevation called the *caruncle* to the outer side of which is a reddish semilunar fold the *plica semilunaris*

The Caruncle is really a small piece of skin containing large modified sweat glands and sebaceous glands that open into the follicles of fine hairs (see also p 150)

The Plica semilunaris represents the third eyelid membrana nictitans of the lower animals It often contains plain muscle tissue supplied by the sympathetic (see also p 151)

At a point in the lids corresponding to the plica semilunaris is a small elevation known as the *papilla lacrimalis* the centre of which is pierced by a hole the *punctum lacrimale* which as we shall see (p 155) serves to carry the tears down into the nose

The puncta divide the lid margins into *ciliary* and *lacrimal portions*

Most normal eyes are practically the same size When we speak therefore of eyes appearing small or large we usually refer not to their actual size but to the amount visible which depends on the size of the palpebral fissure

With the eyes open the outer angle is about 2 mm above the inner and thus the axis of the fissure is not horizontal but slopes from within upwards and out wards

An increase in this obliquity is characteristic of the Chinese and Japanese Moreover *these races have a fold passing from the inner end of the upper lid to* the lower hiding the caruncle—a condition known as epicanthus

Epicanthus occurs normally in the human fœtus (Keith) but disappears with the development of the bridge of the nose It is also seen in congenital ptosis (Pockley 1919) Indeed it has been regarded as dependent upon the flatness of the nasal bones but Duckworth (1904) points out that in the Negroid races whose nasal bones are even flatter than those of the Mongols it is usually absent

When the eyes are open too the palpebral fissure which measures about 30 mm by 15 mm (see table on p 122) is seen to be asymmetrical Its greatest width above the line joining the two angles is on the medial side while below it is on the lateral side When the eyes are shut the outer angle drops

till it lies under the inner and the fissure becomes sinuous concave upwards in its central portion The roots of the lashes give the shape of the fissure except in the lacrimal portion where it is horizontal In its outer part the fissure slopes downwards

The portions of the eye that are normally visible in the palpebral opening are the cornea the iris and pupil, a triangle of sclera to the outer side and a crescent of it to the inner, the caruncle and the plica

The most exposed portion of the globe is a zone just below the centre of the cornea for this remains uncovered even when the eyes are "screwed up" *Hence it is the common site of those congestive or degenerative changes which result from exposure* At the approach of danger the eyes tend to turn up Here the exposed portion will be below, and it is thus this region which will be most *affected by injuries due to burns and caustics, and is also the site of ulceration seen sometimes in the coma vigil of typhoid and other severe illnesses*

Table to show some of the characteristics of the palpebral opening and its relation with certain parts of the globe (from Winckler)

	Length	*Height*	*Pupil*	*Cornea*	*Lacus lac and Plica*	*Position of Transverse Axis*
Newborn	18 5–19 mm	10 mm	Touches free border of lower eyelid	Upper border at level of free margin of upper eyelid	Not visible	Middle of pupil
Infant	24–25 mm	13 mm	Equidistant from free borders of eyelids	Upper and lower borders covered to same extent	Slightly visible	Below middle of pupil
Adult	28–30 mm	14–15 mm	Near free border of upper eyelid	Lower border at level of free margin of lower eyelid	Visible	Lower border of pupil
Old man	28 mm	11–12 mm	Touches free margin of upper eyelid	Lower border a little distance from free margin of lower eyelid	Very visible	Near lower border of cornea

Here we see that the portion of the globe visible between the eyelids is lower as age increases

The Free Margin of each lid is about 2 mm broad, and has an anterior and a posterior border.

From the anterior rounded border jut the eyelashes, which are stiff hairs arranged in two or three rows The upper lashes are longer and more numerous

and curl upwards while the lower ones turn downwards so that they do not interlace when the eyes are shut The lashes are as a rule darker than the hair, and do not become grey with age although they may do so after some diseases (e g alopœcia areata) It takes about ten weeks for a lash which has been epilated to grow to its full size The lashes are longest and most curled in childhood

The Follicles of the Lashes—Although generally like those of hairs elsewhere the lashes have no erector muscles They pass into the lid obliquely in front of the muscle of Riolan to reach the tarsus The lashes are very sensitive being richly supplied with nerves Young lashes are knob shaped and a persistence of this condition is seen in many chronic inflammatory conditions Each lash remains about five months

The Posterior Border of the lid margin is sharp and placed against the globe Just in front of it can be seen the small orifices of the Meibomian glands Between these and the eyelashes is a thin grey line where the lid can be quite easily split into an anterior and a posterior portion

The free margins of the lids have the above characteristics in the *ciliary* portion i e up to the puncta To the inner side of these i e in *the lacrimal portion* there are as a rule no cilia or Meibomian glands Rarely after the age of ten years lashes are found on the lacrimal portion of the lid margins This portion is rounded hence has no borders In its thickness is the lacrimal canaliculus

The Structure of the Lids—The lids consist of a series of layers placed one in front of the other like the leaves of a book

From before backwards we find

1 The skin
2 A layer of subcutaneous areolar tissue
3 A layer of striped muscle
4 The submuscular areolar tissue
5 The fibrous layer—including the tarsal plates
6 A layer of unstriped muscle
7 The mucous membrane or conjunctiva

1 *The Skin* of the eyelids is about the thinnest in the body Hence it forms folds and is easily wrinkled A well marked fold is often seen on the outer side of the upper lid in old people It may overhang the lid margin The skin also is very elastic so that it recovers rapidly after being distended by fluids etc When the eye is open the upper lid is marked at the upper border of the tarsal plate by a furrow the mouth of which gets nearer the lid margin the wider the eye is opened The corresponding furrow in the lower lid is ill marked and often broken up

Also as has been mentioned before furrows exist at times—especially in the old—just beyond the lower orbital margin these are emphasised when the lower

lids are puffed out with fat escaped from the orbit (see also p 130) They are due to attachment of the skin to the orbital margin It is also attached at the inner and outer canthi to the medial and lateral palpebral ligaments, especially the former

Structure.—The epithelium forms a relatively thin layer The stratum corneum is well developed The stratum granulosum is present, the stratum mucosum consists of three or four layers of cells Then comes the stratum germinativum resting on a basement membrane

At the lid margin the epithelium becomes modified as we trace it from the anterior to the posterior border It thickens and contains some 7–10 layers of cells The dermis is denser and richer in elastic fibres, it becomes folded to form papillæ which become higher and narrower, and the basement membrane is correspondingly wavy (Winckler)

The free margin of the lid is, as it were, covered by modified conjunctiva which gets thinner as we trace it anteriorly The line of junction between skin and conjunctiva is at the anterior border and can be seen easily (Winckler) At the transition zone the cells tend to be placed obliquely and almost parallel with the free margin, whereas elsewhere in both skin and conjunctiva they are placed perpendicularly to the surface, numerous lymphocytes are seen in the chorion and there is a change in the thickness of the epithelium

The hairs on the lids, although comparatively large in the fœtus, are more like down in the adult, and have small sebaceous glands connected with them (Fig 99)

The sweat glands, although numerous, are of small size.

Waldeyer described in the skin of the eyelids, in the connective tissue tracts which accompany the vessels, and in the hair follicles, large pigment cells with processes

These cells are found in the skin in most regions of the body but generally are rare, while here they are regularly met with They are more numerous in brunettes than blondes

The pigment is golden yellow or brown These chromatophores may wander and so determine the changes more or less marked in the coloration of the eyelids seen in the same individual in different states of health, etc (Dor)

2 *The Subcutaneous Areolar Layer* consists of loose connective tissue containing no fat, so the skin can easily be lifted off the underlying muscle and also be distended with œdema or blood It is absent near the ciliary margin at the palpebral furrows and at the inner and outer angles where the skin is adherent to the palpebral ligaments

3 *The Layer of Striate Muscle*.—These are the fibres of the orbicularis palpebrarum supplied by the 7th nerve The muscle fibres are arranged concentrically around the palpebral opening The fibres are placed obliquely in relation to each other and overlap as do tiles on a roof The part of this muscle which lies next

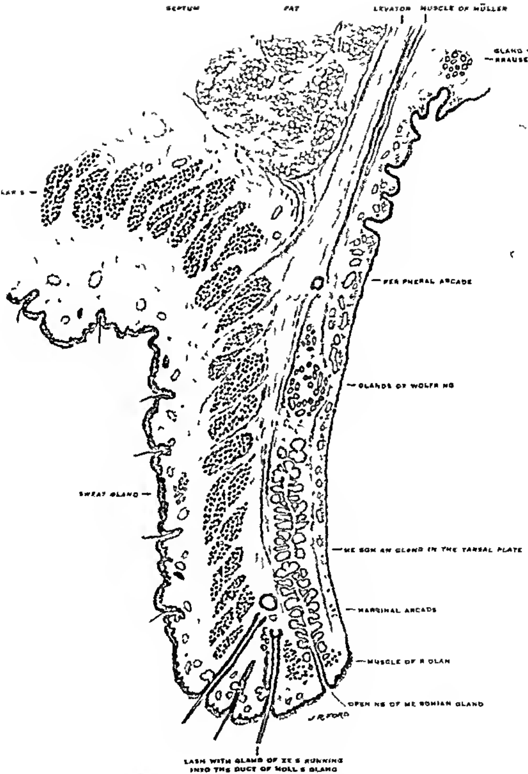


Fig 99 —Vertical Section through the Upper Lid

(After Fuchs and Author's preparations)

and occupies nearly the whole thickness of the lid margin is called the muscle of Riolan (Fig 99) It is traversed successively by the follicles of the lashes the glands of Moll and the excretory ducts of the Meibomian glands (Fig 99) (see also p 136)

4 *The Submuscular Areolar Tissue* resembles the subcutaneous layer It lies between the orbicularis and the tarsal plate and communicates[1] above with the sub aponeurotic layer (the dangerous area) of the scalp (Trotter in Choyce s *Surgery*) Hence pus or blood can make its way into the upper lid from the dangerous area (see also p 140) It is through this plane which is reached by entering the knife at the grey line that the lid may with the greatest ease be split into anterior and posterior portions This space is traversed by the fibres of the levator some of which pass on through the orbicularis while others gain attachment to the lower third of the tarsus The main nerves to the eyelids also lie in this areolar tissue *hence when injecting a local anæsthetic to anæsthetise the lids it is necessary to inject deep to the orbicularis*

In the lower lid this tissue lies in a single small space (the preseptal space) in front of the septum orbitale In the upper lid the space in which the tissue lies is divided by the levator into the pretarsal and preseptal spaces (Charpy and Clare-mont)

The pretarsal space is small It contains the peripheral arterial arcade (Fig 99) It is bounded anteriorly by the levator tendon and the orbicularis posteriorly by the tarsal plate and the muscle of Muller Its upper end corresponds to the place where the muscle of Muller arises from the levator Its lower limit is formed by the attachment of the fibres of the levator to the front of the tarsal plate On vertical section the space is fusiform

The preseptal space is triangular on vertical section It is bounded in front by the orbicularis behind by the septum and those tendinous fibres of the levator which pierce the orbicularis Above is the preseptal cushion of fat

The preseptal cushion of fat is a well defined agglomeration of fat different from the subcutaneous fat It is for the most part in front of the septum and behind the orbicularis Crescent shaped it lies along the orbital margin which it may overlap at times Its lower thicker border is parallel to the upper palpebral furrow The fat is adherent to the orbicularis and the epicranial aponeurosis and thus according to Charpy separates the preseptal space from the dangerous area of the scalp

The pre muscular and retro muscular spaces communicate between the fibres of the orbicularis but are separated by the septum and tarsal plates from the orbit Also infiltrations of the eyelids do not extend on to the cheek and fore head

5 *The Fibrous Layer* —The fibrous layer may be regarded as the framework

[1] See also p 140

of the lids It consists of a thickened central portion the tarsal plates and a thinner peripheral part known as the palpebral fascia or septum orbitale [1]

The Tarsal Plates—one for each of the lids—form the skeleton of the lids giving them their shape and firmness They are often called the tarsal cartilages but consist of dense fibrous and some elastic tissue found mainly around the acini in which are embedded the Meibomian glands They contain no cartilage The outer ends are 7 mm from Whitnall s tubercle The inner ends terminate at the lacrimal puncta some 9 mm from the anterior lacrimal crest

The tarsus is well delimited from the surrounding tissues but laterally at the ciliary margin its connective tissue is closely united with that round the follicles of the lashes to form a characteristic thickening at the margin of the lid (ciliary mass of Whitnall)

The upper tarsus which is shaped like the letter D placed on its side is much larger than the lower being 11 mm in height at its middle The corresponding measurement in the lower tarsus which is somewhat oblong in form is 5 mm

Each tarsus some 29 mm long and 1 mm thick may be described as having an anterior and posterior surface a free and attached border and an inner and outer extremity

The anterior surface of the tarsus is convex and is separated from the orbicularis by loose areolar tissue so that the muscle moves freely on the tarsus

The posterior surface which is concave clothed by and closely adherent to the conjunctiva moulds itself on the globe of the eye

The free border forming the margin of the lid is thick almost horizontal and co extensive with the ciliary portion of the lid margin *the attached border* is thin and gradually runs into the palpebral fascia with which it is continuous except where it is pierced by the levator in the upper lid and the prolongation of the inferior rectus in the lower (see below) The superior border of the upper tarsus gives attachment to the unstriped superior palpebral muscle (Figs 99 and 100) while similarly to the inferior border of the lower tarsus the inferior palpebral muscle is inserted

The extremities of the tarsal plates are attached to the orbital margin by strong *fibrous structures known as the medial and lateral tarsal or palpebral ligaments*

The Medial Palpebral Ligament is a somewhat triangular band which lies on the frontal process of the superior maxilla from the anterior lacrimal crest to near its suture with the nasal bone (Figs 14 113)

The ligament has a lower free border (under which some of the fibres of the orbicularis insinuate themselves) while above it is adherent to and continuous with the periosteum

At the base of the triangle that is at the anterior lacrimal crest the ligament divides into anterior and posterior portions The posterior portion is continuous

[1] Although the term septum orbitale is usually applied to the palpebral fascia only it is the whole fibrous layer which when the eyes are shut forms a septum to the orbital opening

with the lacrimal fascia and thus helps to roof over the upper part of the lacrimal sac

The anterior portion is continued at the inner canthus into two bands which pass across the lacrimal fossa (but not in contact with the sac) to attach it to the medial extremities of the tarsal plates These bands make an angle open outwards with the lacrimal fascia They form with the main ligament a letter Y placed on its side The two branches which correspond to the lacrimal portions of the lid margins and in fact contain the lacrimal canaliculi enclose the caruncle and delimit the inner canthus

The anterior surface of the ligament is free and adherent to the skin It looks forwards and outwards the two branches look forwards and inwards and thus make with it an obtuse angle open forwards

A deep or reflected portion of the medial palpebral ligament is usually described This is said to arise from the main ligament as it crosses the sac and is attached behind the sac The author has never been able to demonstrate this posterior portion satisfactorily,[1] *apart* from the lacrimal fascia and Whitnall (1932) describes it as very thin and of secondary importance appearing in dissections merely as the fascia clothing the front of the pars lacrimalis muscle Only in one full term fœtus did he find it better developed than the anterior portion When the outer canthus is pulled outwards and upwards the medial palpebral ligament forms a well marked prominence

It should be carefully noted that this prominence lies almost entirely on the frontal process of the superior maxilla

A finger placed in the lacrimal fossa lies under the inner angle of the eye

According to Meller the medial canthus corresponds more or less to the anterior lacrimal crest Also if a vertical incision is made 2 mm medial to the inner canthus *the whole of the dissection to expose the sac is made under the outer lip of the wound*

It follows from this and from what has been said above that the lower prominent portion of the medial palpebral ligament does not lie in front of the lacrimal sac, at any rate not for more than a millimetre or two

The Lateral Palpebral Ligament is attached to the orbital tubercle on the zygomatic bone 11 mm below the fronto zygomatic suture It is some 7 mm long and 2 5 mm broad It consists of fibrous tissue which is not very dense

It lies deeper and does not form a prominence as does the medial palpebral ligament Its anterior surface is fused with the preciliary fibres of the orbicularis Superficial also to this ligament are a few lobules of the lacrimal gland and the lateral palpebral raphe formed by the orbicularis and strengthened by the septum orbitale

The posterior surface is in relation to the outer check ligament, separated

[1] Meller also describes the reflected portion of the ligament as being *part of* the deep or lacrimal fascia

however from it by a lobule of the lacrimal gland. Its upper border is united with the expansion of the levator, its lower border with an expansion from the inferior oblique and the inferior rectus (Winckler). It may or may not bifurcate at its inner end to reach the tarsal plates. In the former case the two portions are separated by the outer termination of the muscle of Riolan.

The Palpebral Fascia or Septum Orbitale

The palpebral fascia or septum orbitale is attached to the orbital margin at a thickening called the *arcus marginale*, which is formed where the periorbita is

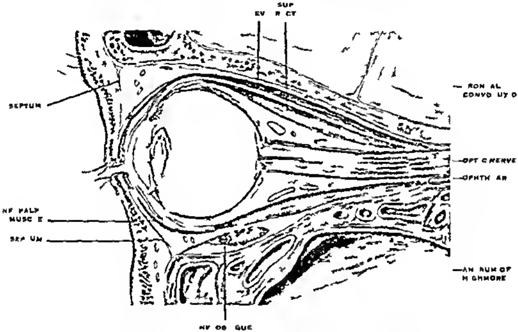


FIG 10.—VERTICAL ANTERO-POSTERIOR SECTION OF THE ORBIT

continuous with the periosteum; centrally it is continuous with the tarsal plates except where it is pierced by the fibres of the levator in the upper lid and the expansion from the inferior rectus in the lower.

The continuity of the septum with the tarsus between the fibres of the levator can only be made out with difficulty by dissection under water and is denied by many observers.

A portion of the septum is also carried forwards with the fibres of the levator and a portion reflected back along its upper surface (Fig 99).

The palpebral fascia must not be regarded as a fixed and rigid structure. It is a floating membrane which takes part in all the movements of the lids, and has been regarded (though this is doubtful) as the deep fascia of the palpebral portion of the orbicularis. It consists of two layers, the fibres of which, running in arcades, cross each other more or less at right angles.

The septum is thicker and stronger on the outer side than on the inner and in the upper lid than in the lower In the upper lid, in fact, two tendon like thickenings can be seen starting from the outer side and gradually becoming lost as we trace them inwards

It is the weak portions of the septum orbitale which determine the site of herniæ of the orbital fat which lies just deep to it These herniæ are seen frequently, especially in old people

The attachment of the septum while more or less following the orbital margin does not do so exactly It does however, mark the junction of periorbita and periosteum

Starting on the outer side we find the septum attached to the orbital margin in front of the lateral palpebral ligament which goes to Whitnall's tubercle, being separated from it by loose connective tissue containing a lobule of fat From here the line of attachment runs upwards, crosses the fronto malar suture, and then follows the posterior lip of the upper orbital margin to the supraorbital notch which it bridges over converting it into a foramen Again following the supraorbital margin, the attachment of the septum passes in front of the pulley of the superior oblique and then, leaving the bone, bridges over the upper and inner angle of the orbital opening with its vessels and nerves, to become again attached to the bone behind the upper part of the posterior lacrimal crest It now runs down on the lacrimal bone behind Horner's muscle and thus behind the lacrimal sac and the medial palpebral ligament and in front of the inner check ligament (Fig 113) The line of attachment crosses the lacrimal sac (or rather the fascia covering it) about its middle, to reach the anterior lacrimal crest at about the level of the lacrimal tubercle From here it follows the lower orbital margin to the point where the malar portion starts ascending Here the attachment leaves the margin and lies actually a few millimetres from it on the facial aspect of the malar bone, so that here the septum forms an osteofibrous pocket, the pre marginal recess of Eisler, which contains fat The line of attachment again reaches the (outer) orbital margin just below the level of Whitnall s tubercle

It will be noted that on the outer side the septum is superficial, lying anterior to the lateral palpebral ligament, while on the inner side it is deep, lying behind Horner's muscle

Where the two parts of Horner's muscle diverge to reach the upper and lower eyelids the portions of the septum belonging to the upper and lower eyelids meet behind the caruncle and plica The inferior medial palpebral artery runs here in a plane between the caruncle and Horner's muscle

Relations.—In the upper eyelid the septum is mainly in contact with orbital fat (continuous with the upper and outer mass of perimuscular fat) This separates the septum from the lacrimal gland, the levator, and the tendon of the superior oblique On the inner side the septum is in contact with that portion of the orbital fat which tends to pass out of the orbit between the pulley of the

superior oblique and the medial palpebral ligament, pushing the palpebral fascia in front of it.

In the lower eyelid the septum lies in contact with those portions of the orbital fat which tend to escape through three orifices and is also in relation to the expansion of the inferior rectus and inferior oblique (Fig. 100).

In the lower lid there is only one space, bounded behind by the septum orbitale and the tarsal plate, and in front by the orbicularis (see p. 134).

The Septum Orbitale is pierced by the following structures:

(*a*) The lacrimal vessels and nerves.

(*b*) The supraorbital vessels and nerves.

(*c*) The supratrochlear nerve and frontal artery.

(*d*) The infratrochlear nerve.

(*e*) The anastomosis between the angular vein and the ophthalmic.

(*f*) The superior and inferior palpebral arteries above and below the medial tarsal ligament.

(*g*) The levator palpebrre superioris in the upper lid and in the lower by a prolongation of the inferior rectus It must be pointed out that many hold that the lower border of the septum and the upper border of the tarsus are not continuous between the fibres of the levator. The muscle would then pass between these two structures.

6. *The Layer of Unstriped Muscle Fibres*, known as the muscle of Muller, lies just deep to the palpebral fascia in both upper and lower lids, and, running for the most part vertically, takes origin among the fibres of the levator in the upper lid and the prolongation of the inferior rectus in the lower.

It is inserted into the attached margins of the tarsal plates (Figs. 99, 100).

The inferior palpebral muscle can, according to Fuchs, be seen through the conjunctiva.

The muscle of Muller is supplied by the sympathetic, and when in action widens the palpebral fissure.[1]

7. *The Conjunctiva* which lines the lids is called the palpebral conjunctiva. It is firmly adherent to the tarsus (see also p. 141).

The Glands of the Lids

Apart from the glands of the skin, which have already been considered, and those of the conjunctiva, we find the following glands in the lids named after those anatomists who first described them:

1. The Meibomian glands.
2. The glands of Moll.
3. Zeis's[2] ciliary glands.

[1] Fibres of unstriped muscle are also found bridging over the spheno-maxillary fissure, and (?) in the capsule of Tenon. The whole system represents the retractor bulbi of some mammalia (see p. 371).

[2] Note spelling—not as Zeiss, the instrument maker.

1 **The Meibomian Glands** are long sebaceous glands which are remarkable in not being connected with hairs; this, however, is due to the fact that they take the place of a row of lashes (see p. 346). They are situated actually in the tarsal plates and running from their attached to their free margins (Fig. 99). The upper ones will therefore be the larger. They are arranged vertically parallel with each other, about twenty-five for the upper lid and twenty for the lower. Each consists of a central canal into the sides of which open numerous rounded appendages which secrete sebum. The small orifices of the canals, whose number is exactly that of the Meibomian glands, can be seen on the margin of the lid just in front of its posterior border (Fig. 112).

TARSAL PLATE

Fig. 101.—Lobules of the Meibomian Gland. (Author's preparation.)

It is here that the sebaceous material is poured *to prevent the overflow of tears, to make for an airtight closure of the lids, and to prevent the tears from macerating the skin* (Fuchs).

The duct is lined by four layers of cells situated on a basement membrane. The mouth of the duct is lined by six layers of cells, of which the deepest are cylindrical. Keratinisation increases as we approach the lid margin.

The acini are usually globular, 10–50 in number, and placed irregularly round the central canal till near its orifice, and so resemble a chain of onions (Winckler).

Each acinus is said to be surrounded by a lymphatic space. The structure of a Meibomian gland is like that of a gland of Zeis (*q.v.*).

The Meibomian glands can be seen easily showing through the conjunctiva as yellow streaks.

2 **The Glands of Moll** may be considered as sweat glands which have become arrested in their development. They are some 1.5 to 2 mm. long and placed obliquely in close relation with and parallel to the bulbs of the cilia. They are more numerous in the lower lid, but even here there is not one to every lash.

Each has a fundus, a body, an ampullary portion and a neck. The cavity is singularly large (Figs. 102, 111) but gets narrower at the neck.

It passes through the dermis and epidermis and may terminate separately

between two lashes or between the lash and its epithelial covering or into the duct of a gland of Zeis (Fig 99)

Structure —The structure of a gland of Moll is much like that of an ordinary sweat gland The secretory portion is lined by a layer of cylindrical cells which contain secretory granules and fatty granulations and between these cells and the basement membrane is placed an ill-defined layer of longitudinal or obliquely placed cells and fibres which are muscular (myoepithelial) in character

The duct is lined by two or three layers of cells the most superficial of which are cylindrical There are no muscle fibres

3 **Zeis s Glands** are modified sebaceous glands which are attached directly to the follicles of the eyelashes (Fig 102) Usually there are two to each cilium Each gland consists of epithelium placed on a basement membrane Next to this membrane is a layer of small cubical cells which are actively dividing The cells resulting from this division enlarge become polygonal and filled with sebaceous granules The nuclei diminish in size become star shaped and disappear The degenerative cells lose their cell walls and are pushed towards the centre of the gland and then towards the secretory duct The sebum passes out between the lash and its epithelial covering

The Blood vessels of the Lids

Arteries —The blood supply to the lids is derived mainly from the *ophthalmic* and *lacrimal* arteries by their *medial* and *lateral palpebral* branches

The medial palpebral arteries—superior for the upper lid inferior for the lower—pierce the palpebral fascia above and below the internal tarsal ligament Each anastomoses with the corresponding lateral palpebral artery from the lacrimal to form the *tarsal arches* whose plane in the lids is in the submuscular areolar tissue (i e between the orbicularis and the tarsal plate) close to the lid margin (Figs 99 and 106)

The Tarsal Arches (*Arcades*) receive anastomosing twigs from the superficial temporal transverse facial and infraorbital arteries

In the upper lid a *second arterial arch* is formed from the superior branch of the medial palpebral It is called the arcus tarseus superior and is situated in front of the upper margin of the tarsal plate (Fig 99 and 106)

From the arches branches pass forwards to supply the orbicularis backwards to the conjunctiva and Meibomian glands

The Veins of the lids are larger and more numerous than the arteries They are arranged in pre tarsal and post tarsal sets and form a dense plexus (which can be seen in the living) in the region of the upper and lower fornices of the conjunctiva

Some of them empty into the veins of the forehead and temple others pass through the orbicularis to reach radicles of the ophthalmic vein

Lymphatics —Like the veins the lymphatics are arranged in *pre and post*

Anteriorly it is separated from the skin, *not* by areolar tissue, but by a layer of *fat*, to which it is adherent, and so acts on the skin, which actually receives only the following fibres, mostly from the periphery of the muscle

(*a*) *The Musculus superciliaris* (Merkel), or depressor muscle of the head of the eyebrow (Arlt), comprises some of the upper medial peripheral fibres which pass to the skin of the inner portion of the eyebrow

(*b*) *The Malaris* (of Henle) is constituted by some of the medial and lateral lower peripheral fibres which are attached to the skin of the cheek Also Merkel has described some fibres which are attached to the skin round the inner canthus, which produce a series of fine lines on the inner part of the lids, especially in those who have small eyes and are subject to frequent blinking (Poirier)

Horner's Muscle,[1] or the **Tensor tarsi** is also called the *pars lacrimalis* of the orbicularis, because it is regarded by some anatomists as forming the deep origin of the pre tarsal portion of the muscle

It consists of a thin layer of fibres which arises behind the lacrimal sac from the upper part of the posterior lacrimal crest (Figs 112 113) which often shows a roughening here The muscle passes outwards and forwards,[2] and divides into two slips, which surround the canaliculi and become continuous with the pretarsal portions of the orbicularis of the upper and lower lids and with the muscle of Riolan The lacrimal fascia and Horner's muscle prevent ectropion of the lower lid after excision of the lacrimal sac when the medial palpebral ligament has been divided (see Whitnall)

The Muscle of Riolan is the ciliary portion of the orbicularis, and consists of very fine striped muscle fibres which lie in the dense tissue of the lids near their margin The glands of Moll separate them from the palpebral portion of the orbicularis

A part of the muscle lies superficial to the Meibomian glands and a part (the subtarsal portion) deep to them (Fig 99)

The muscle of Riolan is continuous medially with Horner's muscle (Fig. 112).

Actions —The orbicularis is the sphincter muscle of the eye

The Palpebral Portion is used in closing the eye without effort. Usually it is an involuntary movement, as in blinking, which goes on continuously almost without our being aware of it People also blink their eyes when they want to see more clearly, often when they are thinking rapidly, to get, as it were, a sharper

[1] First described by Duverney in 1749 Gerlach also described an anterior lacrimal muscle which arises from the posterior aspect of the medial palpebral ligament and passes outwards and backwards above and below the reflected portion of the ligament (?) to mingle with the orbicularis

[2] Students often find difficulty in picturing the relations of Horner's muscle This is best done by closing one's eyes and thinking of one's own lacrimal fossa with Horner's muscle arising behind it It is not difficult then to picture the muscle passing forwards and outwards lateral to the lacrimal sac and after dividing into two portions reaching the inner ends of the marginal portions of the upper and lower eyelids

mental picture of the situation The eyes are closed reflexly when there is any danger to them and curiously enough on hearing a loud noise

The Orbital Portion is used to close the eyes tightly When this portion of the muscle is in action the skin of the forehead, temple, and cheek is drawn towards the inner side of the orbit, the eyelids being firmly closed Radiating furrows are formed, especially on the outer side and below the eye In the young they are only seen when the muscle is acting, later they become permanent, and have received the name of "crow's feet" The muscle comes into play in sudden, short lived conditions bringing an increased supply of blood to the head and eye, and giving rise to a strong expiratory effort Thus it is seen in action in crying children, in coughing, in blowing the nose, sneezing and *excessive* laughing Charles Bell thought that the eye was shut tightly to lessen the vascular dilatation which accompanies these efforts, and thus act as a protective bandage *This action of the orbicularis can be greatly curtailed by drawing the outer canthus laterally or dividing it*

One portion of the orbicularis may be paralysed without the other The orbicularis also holds the lower lid in contact with the globe, since in paralysis of the muscle it falls away and lacrimation results See also the action of the orbicularis in the conduction of the tears (p 162)

Nerve-supply.—The orbicularis belongs to the muscles of facial expression, and hence is supplied by the *7th cranial nerve* by fibres probably coming from the nucleus of the 3rd cranial nerve The upper part of the muscle is supplied by the temporal branch of the facial the lower by the zygomatic branch These branches enter the muscle from the lateral side and on its deep surface

The former crosses the zygoma, as one or more branches, ¾ in behind the external angular process, runs a little above the external canthus, and then parallel with the supraorbital margin (see Fig 155)

The zygomatic branch (or branches) reaches the lower part of the muscle by crossing the cheek By the time these nerves actually enter the muscle they have divided into a fair number of branches (Fig 140)

The Corrugator supercilii (Fig 114) is a small, darkly coloured muscle situated at the inner side of the eyebrow under cover of the frontalis and orbicularis *Arising* from the inner end of the superciliary ridge, it passes upwards and outwards, and then through the overlying muscles (Fig 140), to be *inserted* into the skin of the eyebrow about its middle It is responsible for the gaping of a vertical wound of the eyebrow

Action—The corrugators pull the eyebrows towards the root of the nose, making a projecting roof over the inner angles of the eye and producing characteristic vertical furrows in the middle of the lower part of the forehead and a dimple at its point of insertion.

The muscle is used primarily to protect the eye from the glare of the sun by forming a projecting shelf above it It is well developed in those farm children

who go about in the open without hats These acquire permanent vertical furrows between the eyebrows quite early in life In relation to facial expression it is *par excellence* the muscle of "*trouble*" It is used to express opposition to anything uncomfortable, and is seen in action in the crying child, in sorrow and pain, in frowning, and in retrospect on difficulty As Froriep points out, it is often used in conjunction with the inner part of the frontalis and pyramidalis, producing a peculiar oblique lie of the eyebrows well seen in the head of the Laokoon

Nerve-supply.—7th cranial, through its temporal branch

The Occipito-frontalis consists of the two occipital and two frontal muscles, united together by a large, thin aponeurosis (the galea aponeurotica), which covers and is moulded on the upper part of the cranium

Each *occipital muscle*, small and of a quadrilateral form, arises from the outer two thirds of the superior curved line of the occipital bone and from the base of the mastoid process above the insertion of the sterno mastoid It is inserted above into the epicranial aponeurosis

The frontalis, also somewhat quadrilateral in shape, *arises* by a convex upper border from the epicranial aponeurosis midway between the coronal suture and the orbital margin It is *inserted* into the skin of the eyebrows, mingling with the fibres of the orbicularis and the corrugator Above there is a distinct triangular interval between the two frontal muscles Below, the inner fibres are joined, and intermingle with the pyramidalis but it must be remembered that the latter muscle is running upwards, and is the antagonist of the frontalis

Action—The frontalis raises the eyebrows and draws the scalp forwards, throwing the forehead into a number of transverse wrinkles These furrows are convex upwards on either side, joined by a piece in the centre, usually convex downwards The lines are often absent in the triangular interval between the two muscles above The occipitalis draws the scalp back By the alternate contraction of the two muscles the scalp may be drawn forwards and backwards, a power possessed, however, by very few By the raising of the eyebrows the eyes are widely opened, the white tending to show above the cornea [1]

More light thus reaches the eye, and more therefore is reflected from it, making it brighter and animating the gaze The frontalis is brought into action when vision is rendered difficult, either by the distance of the object or the absence of sufficient light

From the point of view of facial expression, the frontalis, as Duchenne has so well described it, is the muscle of "attention" It is used in expressing surprise, admiration fear, and horror, in all of which the element of "attention" is present If the eyebrows are raised, the lids being half closed, the appearance of forced attention results

Surface Form.—The frontalis is the only muscle of facial expression that can

[1] It thus augments the action of the true elevator of the upper lid—the levator palpebræ superioris.

be seen on the surface, and this only in certain individuals (usually the thin intellectual type) When visible its upper curved border and the triangular interval can be easily made out especially when the muscles are in action

Nerve-supply.—7th cranial

Pyramidalis nasi—*The two muscles of this name placed symmetrically on either side of the midline occupy the bridge of the nose and the interval between the lower portions of the two frontales The muscles arise from the lower portion of the nasal bones and run upwards to be inserted into the skin of the lower part of the forehead on either side of the midline (Fig 140)*

They pull the skin of this region downwards producing transverse furrows in the lower part of the forehead and root of the nose It is for this reason that the somewhat wave like wrinkles of the forehead are convex upwards on either side due to the frontales and tend to be convex downwards in the middle

The pyramidalis is closely associated with the corrugator supercilii It increases the prominence of the eyebrows as a protection when the eyes are exposed to bright light From the point of view of facial expression Duchenne calls it the muscle of aggression or menace Associated with other muscles it expresses painful and similar emotions.

Nerve-supply—*7th cranial*

The frontalis, orbicularis oculi corrugator supercilii and pyramidalis have been called by Howe (1907) the *accessory muscles of accommodation*, since they are brought into play when vision is carried out under difficulties It is possible that the attachment of the frontalis to the occipitalis may explain certain cases of occipital headache due to eye strain (see also p 226)

The Eyebrows

Each eyebrow is a transverse elevation clothed with hairs, and situated at the junction of the forehead and upper lid In structure it resembles the hairy scalp

It consists of the following layers

1 Skin
2 Subcutaneous tissue
3 Layer of muscles
4 Submuscular areolar layer.
5 Pericranium

1 **The Skin** is thick very mobile, and richly supplied with sebaceous glands Like that of the scalp, it is closely adherent to the superficial fascia

The hairs of the eyebrow are hard but silky Taken as a whole they are comma shaped The *head* of the comma the hairs composing which run up wards is placed typically *under* the inner end of the orbital margin The *body* of the comma lies along the orbital margin and the hairs composing it run horizon tally outwards The *tail* of the comma usually lies somewhat above the outer orbital margin whose prominence can be made out *below* it Many variations exist The higher the eyebrow the more curved does it become the lower its position the more horizontal Many muscles of facial expression are attached

to the mobile skin of the eyebrows so that they may be raised lowered or drawn towards the midline

Usually the space between the eyebrows is smooth and hairless (hence glabella) but not infrequently they are joined across the midline

2 **The Subcutaneous Tissue,** like that of the scalp contains little fat and much fibrous tissue It is intimately connected to the skin on the one hand and to the underlying muscles on the other Thus in movements of the eyebrow, the skin subcutaneous and muscle layers move on the submuscular areolar layer

3 **The Layer of Muscles**—This is constituted by the vertical fibres of the frontalis the arched horizontal fibres of the orbicularis and the oblique darker coloured corrugator supercilii

4 **The Submuscular Areolar Layer**—This is a continuation of the dangerous area of the scalp and since the frontalis is *not* attached to the orbital margin it is further continued into the upper lid in the plane between the palpebral fascia and the orbicularis (Trotter)

Charpy, however holds that a deep portion of the epicranial aponeurosis is attached to the orbital margin and cuts off the dangerous area from the lids

The difference between these opposite views is no doubt due to the fact that while clinically blood and pus find their way from the dangerous area into the upper lid the coarser particles of the injection fluid as used by Charpy were held up

Vessels

Arteries

Supraorbital

Superficial temporal

Veins

Internally—to the supraorbital or angular vein

Laterally—to the temporal vein

Lymphatics

Medially they follow the facial vein to the submaxillary group

Laterally they go to the parotid lymphatic glands

The Conjunctiva

The conjunctiva is a thin transparent mucous membrane which derives its name from the fact that it attaches the eyeball to the lids

It lines the posterior surface of the lids and is then reflected forwards on to the globe of the eye becoming continuous anteriorly with the epithelium of the cornea (the conjunctiva corneæ)

It thus forms a (potential) sac the conjunctival sac which is open in front at the palpebral fissure and only closed when the eyes are shut

Although all parts of the conjunctiva are continuous with each other, it is divided for purposes of description into three portions.

That which belongs to the lids is called the **Palpebral Portion**, that clothing the eyeball is the **Bulbar Portion**. The *intermediate* part, forming the bottom of the conjunctival sac where the reflection on to the globe takes place, is called the **Fornix**.

1. **The Palpebral Portion** lining the lids may itself be subdivided into *marginal*, *tarsal*, and *orbital* zones.

The conjunctiva of the margin of the lid is actually a transition zone between skin and conjunctiva proper. It resembles the skin in being covered by stratified epithelium, in the middle layers of which are prickle cells. The structure of the marginal zone is continued on to the back of the lid for about[1] 2 mm. (Parsons) to a shallow groove known as the subtarsal fold,[2] at which the perforating vessels pass through the tarsus to reach the conjunctiva. In the admarginal zone the epithelium consists of about twelve layers and is at least as thick as that of the epidermis. The deepest layer is high cylindrical, the middle layers cubical, the superficial ones flattened, *but no longer keratinised*. As we pass from the lid margin, however, the number of layers decreases, and the superficial cells lose their squamous character. Then in the superficial layers goblet cells, varying greatly in numbers in different individuals, make their appearance (Fig. 111).

The puncta open on to the marginal portion of the conjunctiva, and through them the conjunctival sac becomes directly continuous with the inferior meatus of the nose via the lacrimal passages.

Thus disease from the conjunctival sac may spread to the nose and vice versa.

The Conjunctiva Tarsi is thin, transparent, and very vascular.

The vascularity gives the region its reddish or pinkish colour, and accounts for the fact that it is examined in cases of suspected anæmia.

As the conjunctiva is transparent, the Meibomian glands can be seen through it as yellowish streaks.

The conjunctiva tarsi is intimately adherent to the tarsus; in fact, it is almost impossible to separate the two by dissection. For this reason too it is impossible to cover up gaps in the conjunctiva tarsi, as one can with the bulbar portion, simply by dissecting up neighbouring flaps and drawing them over the bare area.

The Orbital Zone of the conjunctiva lies between the upper border of the tarsal plate and the fornix.

It lies loosely on the underlying involuntary muscle of Muller (Fig. 52). Its surface is thrown into horizontal folds. They are folds of movement, and are deepest when the eyes are open and almost disappear when the eyes are shut (Fuchs). The folds appear after birth.

[1] Virchow, however, reckons this marginal zone as only 0·5 mm.

[2] In the fold foreign bodies are very liable to lodge.

If the area just above the tarsal plate be examined with a loupe it will be found marked by a series of shallow grooves which divide it up into a mosaic of low elevations (Stieda's[1] plateaux and grooves). These elevations are not true papillæ although they may become so in inflammation. This area may encroach on the conjunctiva tarsi but never beyond the middle of the tarsus.

2. **The Fornix Conjunctivæ** is a continuous circular cul de sac which is broken only (on the inner side) by the caruncle and the plica semilunaris.

It is divided for purposes of description into superior, inferior, lateral and medial portions.

The Superior Fornix reaches to the level of the orbital margin some 8–10 mm from the limbus.

The Inferior Fornix extends to within a few millimetres of the inferior orbital margin, 8 mm from the limbus.

The Outer Fornix is placed at a depth of 5 mm from the surface, i e 14 mm from the limbus, and extends to just behind the equator of the globe.

The fornix conjunctivæ is in relation with and adherent to loose fibrous tissue which is derived from the fascial expansions of the sheaths of the levator and recti muscles, and which is easily distensible.

In it are found the glands of Krause and the unstriped muscle of Muller. By means of this fibrous tissue the levator and recti can act on the fornix, deepening it when they contract.

Centrally the fibrous tissue becomes continuous with the tarsus.

In the intertendinous interval, that is, in the diagonal regions of the fornix, the conjunctiva is in relation to the orbital fat, and it is in this region that infiltrations and hæmorrhage, such as arise in fracture of the base of the skull, reach the conjunctiva and may extend to the cornea (Charpy).

The fornix is well supplied with vessels, and a rich venous network can be especially well seen in the inferior fornix, where also the whitish aponeurotic expansion from the inferior rectus and inferior oblique shows through the conjunctiva (Fuchs).

A knife passed through the upper fornix will enter the fibrous tissue between the levator and superior rectus, while through the inferior fornix the knife will hit the aponeurotic expansion from the inferior rectus and inferior oblique (Fig. 100).

3. **The Bulbar Conjunctiva** is thin and so transparent that the white sclerotic shows through it, giving rise to the "white of the eye."

It lies loosely on the underlying tissues, so that it can easily be moved apart from them. This movement takes place slightly with all movements of the eye; it is made evident in the living by pressure on the conjunctiva through the lower lid, and the operator knows how easy it is to pick up a fold of bulbar conjunctiva with forceps.

[1] See H. Virchow, *Graefe Saem. sch.*, vol. i, pt. 1.

The bulbar conjunctiva is at first in relation to the tendons of the recti muscles covered by Tenon's capsule

Thus, *in exposing these tendons, for instance in tenotomy, we must divide the conjunctiva, then the capsule of Tenon before they are reached*

In front of the insertion of the recti tendons the bulbar conjunctiva lies on the anterior portion of Tenon's capsule Up to a point about 3 mm from the cornea the conjunctiva is separated from the capsule of Tenon by loose areolar tissue, in which we find the subconjunctival vessels, and between it and the sclera is the loose episcleral tissue in the anterior portion of Tenon's space In this space we find the anterior ciliary arteries, which form the pericorneal plexus, and the tendons of insertion of the recti muscles

At about 3 mm from the cornea, the conjunctiva, Tenon's capsule, and sclera become much more closely united [1]

At the point of union the conjunctiva is sometimes raised by a slight ridge, which becomes very apparent in certain inflammatory conditions, notably spring catarrh This portion of the conjunctiva is known as the *limbal conjunctiva*

The Structure of the Conjunctiva varies fundamentally in its different portions On this depends the limitation of certain pathological processes to definite areas (Parsons)

Only in the new born is the conjunctiva really normal, for owing to its exposed condition slight pathological changes are apt to take place from the earliest age

The conjunctiva, like all other mucous membranes, consists of two layers—*the epithelium and the substantia propria*

The Epithelium.—As has been said before, the marginal portion of the conjunctiva has the structure of skin, but is not keratinised

The conjunctiva is not uniform in thickness It consists, as classically described of two [2] layers The deeper layer is composed of *flattened* cells whose oval nuclei lie with their axes parallel to the surface The superficial layer consists of tall *cylindrical cells*, whose oval nuclei lie near the base of the cells and have their long axis at right angles to the surface

As the fornix is approached, there is a tendency for a third layer of polyhedral cells to be inserted between the other two *So that at the fornix, although generally the structure is like that of the palpebral conjunctiva, we often find three layers instead of two*

From the fornix to the limbus the epithelium becomes less and less glandular

[1] For this reason although it is more difficult to raise a fold of conjunctiva close to the cornea a much firmer hold can be obtained here with forceps than elsewhere (see Terrien) If, however, the underlying tendon of a rectus muscle be included in the grip of the forceps good fixation can be obtained at some distance from the cornea

[2] Although this is the classical description one usually finds numerous areas in the adult palpebral conjunctiva (which cannot be regarded as pathological) where the epithelium consists of many layers (Fig 104)

with a disappearance of the goblet cells, and more like that of the epidermis, but it never becomes keratinised

More and more polyhedral layers are added between the superficial and deep cells The superficial cells become flatter, while the deep cells grow taller At the limbus the epithelium is definitely stratified with the formation of papillæ, which give the deep aspect of the epithelium a characteristic wavy outline (Fig 22) Here the deepest or basal cells form a single layer of small cylindrical or cubical cells, with a large, darkly staining nucleus and little protoplasm It is this fact that produces the *dark line* or seam seen under the low power of the microscope, and characteristic of the bulbar conjunctiva (Fig 22) Moreover, the basal cells often contain pigment granules

There are several layers of polygonal cells, and superficially one or two layers of flattened cells with oval nuclei parallel to the surface

The polygonal cells differ from those of the cornea in having no prickles between them At the limbus in the angle between the epithelium and the sclerotic the chorion of the conjunctiva, Tenon's capsule, and the episclera are fused into a dense tissue

FIG 104 —SECTION OF THE PALPEBRAL (ORBITAL) CONJUNCTIVA TO SHOW GOBLET CELLS
(*Author's preparation*)

Goblet Cells occur in all portions of the conjunctiva, but are most numerous in the fornices, especially the lower one, and on the plica semilunaris (Fig 108)

They are large, oval, or round cells which look like fat cells The nucleus is flattened and is near the base of the cell (Fig 104)

They are said to be formed from the deepest[1] layer of the conjunctiva, i e from the cylindrical cells, and then to pass towards the surface, tending, however, to remain attached to the basement membrane by a pointed process

At first rounded, they grow larger and more oval as they approach the surface, where they resemble the goblet cells of the large intestine, but differ from these in being destroyed once they have discharged their contents

The superficial goblet cells, too, have a stoma, through which the contents of the cell, mainly mucin, is discharged

The goblet cells are true, unicellular mucous glands, moistening and protecting the conjunctiva and cornea, so that even extirpation of the lacrimal gland becomes innocuous, whilst on the other hand xerosis of the conjunctiva, involving their destruction, leads to desiccation, in spite of a copious flow of tears (Parsons, Greeff)

[1] While this is the usual description Löhlein, the author, and others have never seen goblet cells in the basal layer

Although goblet cells occur normally in the conjunctiva they are greatly increased in inflammatory conditions

Melanoblasts, or cells of *Langerhans*, are present in the *conjunctiva* of the coloured races In the white races the cells are present but not usually pigmented The melanin can, however always be brought out by the Dopa reaction or the silver stain of Masson The pigment is manufactured by the cells of Langerhans whose body lies in the chorion

These cells are found at the limbus at the fornix in the plica and caruncle and at the site of perforation of the anterior ciliary vessels

The Conjunctival Glands

The Glands of Krause are accessory lacrimal glands placed between the tarsus and the inferior lacrimal gland, of which indeed they are off shoots They are large serous, acino tubular glands having the same structure as the main lacrimal gland (Fig 99)

There are forty two in the upper and six to eight in the lower fornix (W Krause) Their ducts unite into a large duct or sinus, and open into the fornix

The Glands of Wolfring and Ciaccio are larger than the glands of Krause, but have the same structure

There are two to five in the upper lid, situated actually in the upper border of the tarsus, about its middle, between the extremities of the Meibomian glands

Henle's "Glands" occur in the palpebral conjunctiva between the tarsal plates and the fornices They are probably not true glands, but folds of mucous membrane cut transversely They resemble Lieberkuhn's crypts in the large intestine, and are lined by epithelium, which is like that of the surrounding conjunctiva

The Glands of Manz are saccular or utricular glands found at the limbus in the pig, calf, and ox They have also been described in the human, but this is not generally accepted

The Substantia Propria consists of two portions—a superficial adenoid layer and a deeper fibrous layer The adenoid layer is not present at birth, but is formed first in the region of the fornix at 3 to 4 months It is the formation of this adenoid layer, together with a general increase in the surface area of the conjunctiva, that produces the folds in the upper part of the palpebral conjunctiva at the fifth month (Raehlmann)

The Adenoid Layer is thin, but most developed in the fornix, being here 50–70 μ in thickness (Villard) It consists of a fine connective tissue reticulum, in the meshes of which the lymphocytes lie This layer ceases at the subtarsal fold, so that the lymphocytes which are normally present under the conjunctiva in large numbers are not found in the marginal conjunctiva (Fig 99)

Although nodules of lymphocytes are found in the human conjunctiva, especially towards the angles they usually fade off at the periphery, and do not form true follicles such as are found especially in the lower fornix of the dog, cat, rabbit, etc Pathological development of these nodules leads to the formation of undulations on the surface—pseudo papillæ (Parsons)

The Fibrous Layer is generally thicker than the adenoid, but is almost non existent over the tarsus, with which it is continuous

Actually this layer belongs rather to the subconjunctival connective tissue than to the conjunctiva It is formed posteriorly by the expansions of the sheaths of the levator and recti muscles and anteriorly by the capsule of Tenon

In it are found the vessels and nerves to the conjunctiva the unstriped muscle of Muller, and Krause s glands, which are as it were encapsuled by it (Villard)

Conjunctival Papillæ.—True papillæ are found only at the limbus (Fig 22) and at the lid margins

Those near the limbus are finger like extrusions of the substantia propria, the interspaces of which are filled with epithelium whilst the surface of the epithelium remains flat There are usually only four or five large papillæ (50 µ high) near the cornea, and three or four smaller ones more peripherally (Villard, quoted by Parsons)

The plateaux (and grooves) found at the upper border of the tarsus are not true papillæ but may become so pathologically Virchow also described papillæ over the whole of the conjunctiva tarsi but this is denied by most other observers

Arteries —The arterial supply of the conjunctiva comes from three sources

1 The peripheral arterial arcades
2 The marginal arterial arcades
3 The anterior ciliary arteries

Of these so far at any rate as the upper lid is concerned the peripheral arcade supplies by far the greatest area i e almost the whole of the conjunctiva tarsi, the fornix, and the bulbar conjunctiva up to 4 mm from the cornea

The Peripheral Arcade in the upper lid is situated at the upper border of the tarsus, between the two portions of the levator (Fig 106 99 100) It gives off the peripheral perforating branches, which pass above the tarsal plate and pierce the muscle of Muller to reach the conjunctiva, under which it sends branches upwards and downwards

The descending branches supply nearly the whole of the tarsal conjunctiva They run perpendicularly to the lid margin, and anastomose with the much shorter branches of the marginal artery which have pierced the tarsus at the subtarsal fold

The zone of anastomosis is but slightly vascular (Langer)

The ascending branches pass upwards to the fornix, then bending round this, descend under the bulbar conjunctiva as the posterior conjunctival arteries (Fig 106) They pass towards the cornea at 4 mm, from which they anastomose

with the anterior conjunctival arteries branches of the anterior ciliaries The posterior conjunctival vessels are mobile, moving with the bulbar conjunctiva.

The peripheral arcade of the lower lid is, when present, placed in front of the inferior palpebral muscle of Müller and then generally behaves as does that of the upper lid But it is inconstant and may come from other arteries beside the lacrimal, for instance, the transverse facial or superficial temporal

It is often absent, in which case the conjunctiva of the lower lid, the lower fornix, and inferior portion of the bulbar conjunctiva get their blood supply from the marginal arcade or from the muscular arteries to the inferior rectus (Fuchs)

The Marginal Arcade sends its perforating branches through the tarsus to reach the deep surface of the conjunctiva at the subtarsal fold

These branches divide into *marginal* and *tarsal* twigs

The marginal arterioles run perpendicularly to the lid margin, forming a very vascular zone , the tarsal arterioles run perpendicularly to meet the corresponding branches from the peripheral arcade

The tarsal conjunctiva is well supplied with blood, hence its red colour The colour diminishes as we pass towards the fornix and the bulbar conjunctiva is colourless except when its vessels are dilated due to inflammation

The Anterior Ciliary Arteries come from the muscular arteries to the recti (Figs 37, 106 and 107) Each muscular artery gives off two anterior ciliaries, except that to the external rectus, which supplies only one

The anterior ciliary arteries pass forwards on a deeper plane than the posterior conjunctival They are, however, visible, but appear darker than the superficial vessels Some 4 mm from the cornea scleral junction they bend towards the interior of the eye and pierce the sclera to join the circulus iridis major, which they help to form (Figs 37) The hole in the sclera is often marked by pigment

At the bend the anterior ciliaries give off the *anterior conjunctival arteries*, which pass forwards at a deeper level than the posterior conjunctival vessels (Fig 106) They do not move with the conjunctiva They pass forwards and, anastomosing with each other, form a series of arcades parallel to the corneal margin which more anteriorly gives place to the pericorneal plexus, while posteriorly they send twigs which anastomose with the posterior conjunctival arteries

The pericorneal plexus is arranged in two layers a superficial *conjunctival* and a deep *episcleral* (Figs 22, 19)

The superficial portion is injected in superficial affections of the cornea, while the deeper portion is hyperæmic in diseases of the iris, ciliary body, or deep portion of the cornea

It is the dilatation of the deeper portion which gives rise to the characteristic rose pink band of "ciliary injection" It will be noted that the redness disappears on pressure, but the vessels do not move with the conjunctiva

In conjunctivitis the bulbar conjunctiva becomes brick red, due to hyperæmia of the close network of small superficial vessels which, derived from the posterior conjunctival, are normally almost invisible. The redness increases towards the fornices and gets less as we approach the cornea; it does not fade on pressure. The vessels move with the conjunctiva.

All the above facts are explained by the anatomical arrangements of the vessels. Thus we see that although joined by anastomoses the areas supplied by the palpebral arcades on the one hand and that which gets its blood supply from the anterior ciliaries on the other hand are more or less sharply differentiated, and in affections

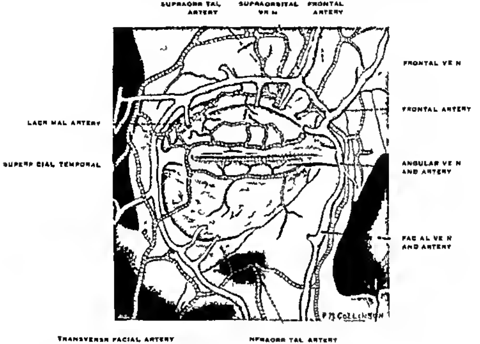


Fig. 105.—The Blood supply of the Eyelids.

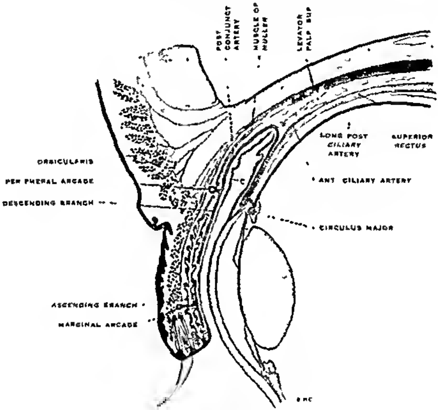
of the conjunctiva the vessels of the former area are injected, the redness increasing towards the fornix, while in deep inflammation, that is of the iris and ciliary body, the network of vessels around the cornea coming from the anterior ciliaries forms a characteristic rose pink band.

In interstitial keratitis the new vessels that invade the substantia propria of the cornea come from the anterior ciliaries as these are passing through the sclera to reach the iris and ciliary body. They are thus, since the sclera is opaque, only visible up to the limbus.

The Conjunctival Veins accompany but are much more numerous than the corresponding arteries. For the most part, i.e. from the conjunctiva tarsi, from the fornix, and the major portion of the bulbar conjunctiva, they drain into the palpebral veins.

Corresponding to the peripheral arterial arcade of the upper lid, there is an important and well-marked venous plexus, which, placed between the tendons of the levator, sends its blood back to the veins of the levator and superior rectus, which again drain into the ophthalmic (Fuchs).

In the circumcorneal zone supplied by the anterior ciliaries the corresponding veins are less conspicuous than the arteries. They form a network some 5 to



C = Conjunctiva

FIG 106.—SECTION OF THE UPPER LID AND ANTERIOR PORTION OF THE EYE TO SHOW THE BLOOD SUPPLY TO THE CONJUNCTIVA.

6 mm wide, which drains into the muscular veins. It becomes apparent in hyperæmia (Merkel).

Lymphatics.—The *conjunctival lymphatics are arranged in two plexuses.*

A superficial, composed of small vessels, placed just beneath the vascular capillaries; and a deep, consisting of larger vessels situated in the fibrous layer of the conjunctiva, and receiving the lymph from the superficial plexus.

They drain towards the commissures, where they join the lymphatics of the lids those from the outer side go to the parotid nodes, and those from the inner to the submaxillary lymph glands.

Nerves.—The nerve supply of the conjunctiva is derived from the same source

as that of the lids generally, but the anterior ciliaries supply the cornea and circumcorneal zone of the conjunctiva and the lacrimal and infratrochlear supply a much larger area of conjunctiva than of skin

Nerve Endings.—The nerves may end in

(*a*) Free endings

(*b*) In the end bulbs of Krause, and, according to Crevatin, in

(*c*) Tufts, or

(*d*) Ribbons

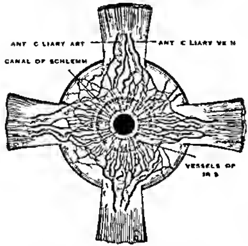


Fig 107.—Anterior Ciliary Arteries and Veins

(*From Leber after Parsons*)

(*a*) *Free Endings*.—The nerves having lost their myelin sheath, form a *sub epithelial* plexus in the superficial part of the substantia propria From this fibres pass to form an intra epithelial plexus around the bases of the epithelial cells and send free nerve fibrils between these cells

(*b*) *The End Bulbs of Krause* are round or ovoid bodies from 0 02 mm to 0 1 mm in length Each is surrounded by a connective tissue envelope continuous with the nerve sheath and lined by endothelial cells In this is found a twisted mass of fibrils One or two nerves enter the envelope, lose their myelin sheath, and join the central mass

These end bulbs are especially abundant in the upper and outer part of the conjunctiva in the area supplied by the lacrimal nerve (Ciaccio), but are also numerous around the cornea and the marginal portion of the lids

The Caruncle (Figs 14 and 108)

The caruncle (diminutive of Latin, *caro*, flesh) is a small fleshy looking ovoid body some 5 mm in height and 3 mm broad, situated in the lacus lacrimalis to the inner side of the plica semilunaris

It is attached to the plica, and fibres of the internal rectus sheath enter its deep surface Thus it is most prominent when the eye looks outwards, being pulled on by the plica, and becomes deeply recessed when the eye looks inwards *and sometimes following tenotomy of the internal rectus*.

It is really a piece of modified skin, so is covered by modified stratified epithelium, and is supplied with hairs, sebaceous and sweat glands It differs from the skin in containing glands like those of Krause *The epithelium* resembles that of the lid margin and the superficial layer is also not keratinised Also towards the conjunctiva, goblet cells are found These may occur singly or in groups, forming a kind of acinus

The Sebaceous Glands resemble those of Zeis and Meibomius They produce the characteristic white secretion not infrequently found at the inner canthus

The Modified Lacrimal Glands are often conspicuous structures They do not represent the gland of Harder which is absent in the human

The Hairs some fifteen in number are fine colourless and directed towards the nose

In the depth of the caruncle the abundant connective tissue is in relation with the septum orbitale and the medial check ligament

Blood-supply —The superior medial palpebral artery The branches to reach the caruncle have to pass through dense connective tissue This keeps them patent when cut and results in free bleeding as does a similar arrangement in the scalp

Lymphatics —These drain into the submaxillary lymph glands

Nerve-supply —The infratrochlear nerve

The Plica Semilunaris

The plica semilunaris is a narrow crescentic fold of conjunctiva placed vertically with its concavity facing outwards and lying lateral to and partly under cover of the caruncle *Its lower horn reaches to the middle of the lower fornix while* the upper does not pass up so far The outer border is free and separated from the bulbar conjunctiva by a small cul-de-sac some 2 mm deep present when the eye looks inwards but almost disappearing when the eye looks outwards The pink colour of the plica is due to its vascularity (Fig 108) and contrasts with the white of the sclera In structure it is like that of the rest of the bulbar conjunctiva but the epithelium instead of six layers consists of eight to ten and the deepest layer *instead of being cubical is cylindrical* and it contains a lobule of fat and some unstriped muscle supplied by the sympathetic Goblet cells are particularly numerous (Fig 108)

The goblet cells may be superficial or grouped and then open on the surface by a narrow duct (intra-epithelial gland of Turneau) Chromatophores called cells of Langerhans are always present They may be non pigmented in fair people but can always be demonstrated by the Dopa reaction and in other ways

The connective tissue stroma of the plica is loose and contains numerous vessels and sometimes a nodule of cartilage At the base of the plica there is a *lobule of fat and sometimes some unstriped muscle fibres*

Similar structures are found in relation to the caruncle and come from the internal rectus and more especially from the medial capsulo palpebral muscle of Hesser

The plica represents the 3rd eyelid[1] or nictitating membrane of the lower animals Lindsay Johnson (quoted by Teacher Collins *Trans Ophth Soc* 1921 xli) saw a boy who had an obvious nictitating membrane which reached almost up to the cornea and was capable of slight movement

[1] *Stibbe (1928) however is opposed to this view*

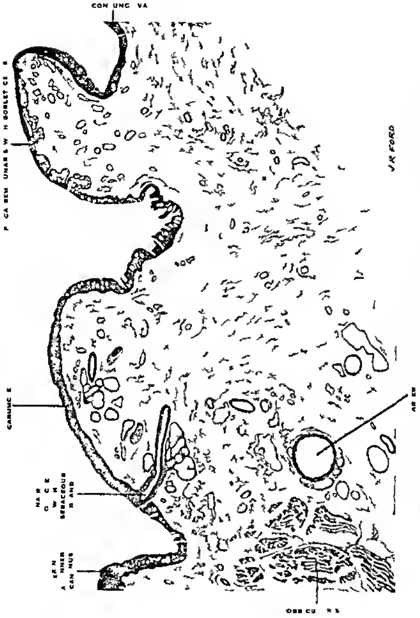


FIG 108 —HORIZONTAL SECTION THROUGH THE CARUNCLE AND PLICA SEMILUNARIS (Author's preparation)

THE LACRIMAL APPARATUS

The lacrimal apparatus is constituted as follows

The lacrimal[1] gland situated above and to the outer side of the globe of the

[1] The lacrimal gland and its tears are only present in those animals which live in air. In fishes for instance there is no lacrimal gland the water in which they live acting in place of tears

eye secretes the tears and pours them through a series of ducts into the conjunctival sac at the upper fornix

The tears now moisten the front of the eye, lubricate it, prevent friction between globe and lids, and also desiccation of the corneal epithelium [1]

Some of the tears evaporate, but the rest make their way inwards to the lacus lacrimalis, where they pass into the puncta situated in the margin of the lids From here they are conducted by the (lacrimal) canaliculi to the lacrimal sac, and then pass into the nasal duct, which opens into the inferior meatus of the nose

The Lacrimal Gland

The Lacrimal Gland consists of two portions (Figs 142, 146, and 147)

(i) A large orbital or superior portion ,

and (ii) A small palpebral or inferior portion ,

which are, however, continuous behind *The Orbital Portion* is lodged in its fossa on the anterior and outer part of the roof of the orbit It is shaped like an almond, and hence we have for examination a superior and inferior surface , an anterior and posterior border, and an inner and an outer extremity

The Superior Surface is convex, and lies in the fossa on the frontal bone, with which it is connected by weak trabeculæ

The Inferior Surface, slightly concave, lies successively on the levator palpebræ, the expansion outwards of this muscle, and the external rectus (Figs 144 and 146)

The Anterior Border is sharp and in contact with the septum orbitale

Hence, to reach this portion of the lacrimal gland from the front, one has to divide skin, orbicularis, and septum orbitale

The Posterior Border, more rounded, is in relation with the orbital fat in the same coronal plane as the posterior pole of the eye

The Inner Extremity rests on the levator—the *outer* on the external rectus

The Palpebral Portion, also flattened from above down, is about one third the size of the orbital portion, and placed so that the anterior border lies just above the outer part of the upper fornix It can be seen in this situation through the conjunctiva when the upper lid is everted

It lies for the most part on the palpebral conjunctiva, but partly also on the superior palpebral muscle

It is separated from the superior portion by the expansion of the levator, but behind this its posterior border is in part continuous with the rest of the gland (Fig 146)

The Glands of Krause (Fig 141) are accessory lacrimal glands occurring under the conjunctiva from the fornix to the convex border of the tarsus They may

[1] Normally this goes on without our being aware of the process either visually or mentally But in crying and other conditions, when excessive tears are produced these overflow the lid margins and by their macerating action produce the characteristic 'red' eyes of crying

be regarded as a continuation downwards of the palpebral portion of the lacrimal gland.

Fine Ducts pass from both portions of the lacrimal gland to open by ten to twelve small orifices just in front of the outer part of the superior fornix. One or two also open into the outer part of the lower fornix.

FIG. 109.—SECTION OF THE LACRIMAL GLAND.
(Author's preparation.)
D = one of the ducts.

Structure.—The lacrimal gland is a tubulo-racemose gland with short branched gland tubules resembling the parotid in structure (Fig. 109). It consists of masses of lobules, each being about the size of a pin's head. It is not very sharply differentiated from the surrounding adipose tissue, and fat is also found between the lobules.

The acini consist of two layers of cells placed on a thin hyaline basement membrane and surrounding a central canal. The cells of the basal layer are myoepithelial in character and are flat and contractile; the other cells are cylindrical and form the true secreting cells. At rest these contain granules. After secreting for some time the cells become shorter and the granules disappear. The secretion of the acini passes into very small interlobular ducts opening into slightly larger ducts which are, however, still intermediary. These finally open into the definitive excretory duct.

The smaller ducts have much the same structure as the acini, but in the large ducts outside the basement membrane is a fibrous coat.

The inter-acinous and inter-lobular connective tissue is hardly present in the young but increases with age. In it are found plasma cells and lymphocytes which may be aggregated into follicles.

The ducts from the orbital portion traverse or are in contact with the palpebral portion. *It thus comes about that removal of the palpebral portion practically does away with the secretion of the whole gland.*

So called ligaments have been described in connection with the lacrimal gland none however, deserve the name

(a) *Superior* to the lacrimal fossa (= suspensory ligament)

(b) *Inferior*—inferior pole to zygomatic bone

(c) *Posterior*—where the lacrimal nerve and vessels enter to the periorbita

(d) *Internal*—accompanying the ducts

Vessels —The lacrimal artery which enters it on its posterior border and sometimes a branch of the infraorbital The corresponding vein joins the ophthalmic

Lymphatics to the conjunctival lymphatics and thence to the preauricular glands

Nerves.—Lacrimal great superficial petrosal and sympathetic

The Fibres of the Great Superficial Petrosal the nerve of tear secretion arise in the cells of the nucleus of the glosso pharyngeal

They pass out in the pars intermedia of the 7th to the geniculate ganglion (but make no cell station here) from which the great superficial petrosal arises

This runs in a groove on the front of the petrous temporal (Fig 139) then under the Gasserian ganglion to join the great deep petrosal (from the sympathetic plexus round the internal carotid artery) to form the Vidian nerve in the cartilage of the foramen lacerum medium (Fig 153)

The Vidian (nerve of the pterygoid canal) joins the spheno palatine (Meckel s ganglion) where it makes a cell station From here fibres pass to the zygomatic nerve and reach the lacrimal gland via the anastomotic branch with the lacrimal nerve

The Sympathetic Fibres come from the superior cervical ganglion via

(a) Sympathetic nerves on the lacrimal artery

(b) Great deep petrosal

(c) Sympathetic fibres in the lacrimal nerve

The Puncta

Each punctum lacrimale is a small round or transversely oval aperture situated on a slight elevation *the papilla lacrimalis* at the inner end of the lid margin at the junction of its ciliary and lacrimal portions It is in a line with the openings of the ducts of the Meibomian glands the nearest of which is only 0 5 to 1 mm away

The region of the punctum is relatively avascular and so is paler than the surrounding area This pallor is emphasised on drawing the lower lid outwards, *a fact of great value in finding a stenosed punctum*

The upper punctum is slightly farther to the nasal side (being 6 mm from the inner canthus) than the lower which is 6 5 mm from this point Thus when the eye is shut the puncta are not in contact but the upper lies to the inner side of the lower

The upper punctum looks downwards and backwards and the lower upwards and backwards so as always to bathe in the tear lake *For this reason too a normal punctum is only visible if the lid is everted*

Each punctum when the eye is opened or shut glides in the groove between the plica semilunaris[1] and the globe, and is kept patent by a ring of very dense fibrous tissue continuous with the tarsus which surrounds it Around this again are fibres of the orbicularis which have a sphincteric action Their atrophy in old age makes the papilla lacrimalis more prominent

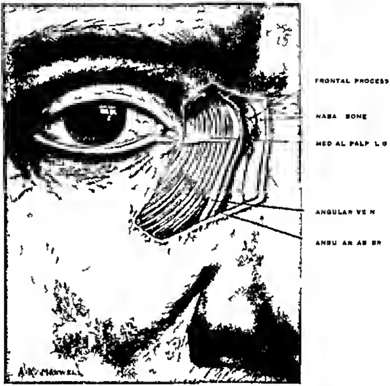


FIG 110 —DISSECTION TO SHOW LACRIMAL APPARATUS RELATION OF ANGULAR VEIN AND ARTERY TO MEDIAL PALPEBRAL LIGAMENT
(Author's dissection)

THE CANALICULI

Each canaliculus consists of a vertical and a horizontal portion *It is therefore of great importance in passing a probe to remember that the canaliculus runs at first vertically*

The vertical portion is about 2 mm long and then bends inwards almost at

[1] I e when the eye is looking straight ahead When it looks outwards it glides in the groove between the plica and the caruncle

a right angle to become continuous with the horizontal portion. At the junction of the two is a dilatation or *ampulla*.

Both horizontal portions slope towards the inner canthus; thus the upper runs downwards as well as inwards, while the lower has a slight inclination upwards. Some 8 mm. long, the upper being slightly the shorter, they lie in the lid margin.

The canaliculi pierce the lacrimal fascia (i.e. the periorbita covering the

FIG. 111.—HORIZONTAL SECTION OF THE INNER PORTION OF THE LOWER EYELID, SHOWING THE LACRIMAL CANALICULUS AT THE JUNCTION OF THE VERTICAL AND HORIZONTAL PORTIONS, SURROUNDED BY FIBRES OF THE ORBICULARIS.

MO = gland of Moll. Note goblet cells in conjunctiva

(Author's preparation.)

lacrimal sac) separately as a rule, then unite to enter a small diverticulum of the sac called the sinus of Maier (Fig. 114).

The point of entry lies just behind the middle of the lateral surface of the sac about 2½ mm. from its apex.

Structure.—The canaliculi are lined by stratified squamous epithelium (Fig. 111) placed on a corium rich in elastic tissue. The walls are thus so thin and elastic that the canaliculus can be dilated three times its normal diameter, which is

0 5 mm For the same reason, in pulling the lids outwards and in passing a probe the angle between vertical and horizontal portions can be easily straight ened Also being so close to the edge of the lid and covered by translucent tissue, a coloured fluid injected into the canaliculus can be seen

Like the punctum the canaliculus is surrounded by fibres of the orbicularis (Fig 111), which on contraction tend to invert the lower lid and draw the punctum inwards so as to make it dip into the lacus lacrimalis

The inner third of the canaliculi is covered in front by the two bands which connect the medial palpebral ligament to the tarsi, while behind this portion is Horner's muscle

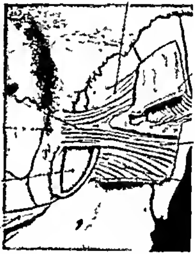


FIG 112—THE RELATIONS OF THE LACRIMAL SAC AND HORNER S MUSCLE THE LIDS HAVE BEEN TURNED OVER ON TO THE NOSE (Author's dissection)

THE LACRIMAL SAC

The membranous lacrimal sac is placed in the lacrimal fossa (formed by the lacrimal bone and the frontal process of the superior maxilla) which lies in the anterior part of the inner wall of the orbit (see also p 4)

The sac is closed above and open below where it is continuous with the nasal duct, a constriction marking the junction between the two

Looked at from the side the sac and fossa are seen to slope backwards 15–25°, the line being given by joining the inner canthus to the 1st upper molar of the same side

From the front the sac slopes gently outwards the duct slightly inwards The two thus make an obtuse angle open inwards (Fig 114)

The sac is enclosed by a portion of the periorbita which, splitting at the posterior lacrimal crest, encloses the sac to meet again at the anterior lacrimal crest, and thus forms what is called the *lacrimal fascia* (Figs 112, 113, 114)

The lacrimal fascia is separated from the sac by areolar tissue containing a fine plexus of veins continuous with that around the duct, except at the fundus, where it is closely adherent, and, sometimes, on its inner aspect

Relations — *Medially* the sac is in relation above with the anterior ethmoidal air cells (Fig 3) (which may also at times lie behind and even in front of the sac) below with the middle meatus of the nose Between bone and sac however, we always find lacrimal fascia

Lateral are the skin fibres of the orbicularis and the lacrimal fascia

For the relation of the medial palpebral ligament to the sac see p 127

The inferior oblique arises from the floor of the orbit just lateral to the lacrimal fossa a few fibres often taking origin from the lacrimal fascia

The angular vein is the great bugbear in the approach to the lacrimal sac Lying under the skin it crosses the medial palpebral ligament 8 mm from the

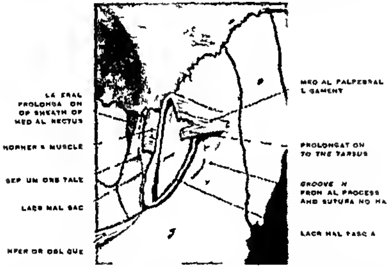


Fig 113 — The Relations of the Lacrimal Sac

(Author's dissection)

inner canthus Not infrequently a tributary of the angular vein which can also be seen in the living crosses the ligament between the medial canthus and parent vein *It is therefore not safe to make the incision for the removal of the sac more than 2 to 3 mm medial to the inner canthus*

The lower margin of the medial palpebral ligament is free but it is continued upwards and laterally as a sheet which blends with the lacrimal fascia covering the fundus of the sac (see p 127)

As Fisher points out this attachment to the sac may explain how relatively slight blows on the eye (as in boxing) may cause swelling of the lids on blowing the nose A sudden strain is put on the ligament which pulls on and tears the sac

The portion of the sac below the level of the ligament is only covered by a few fibres of the orbicularis which offer little resistance to distension and swellings of the sac *It is therefore in the area below the ligament that abscesses and fistulæ will open*

Behind the sac are the lacrimal fascia and Horner's muscle which takes origin from the upper half of the posterior lacrimal crest runs behind the sac and

covers the posterior aspect of the medial third of the canaliculi Behind this again is the septum orbitale, and then comes the check ligament of the medial rectus (Fig 113)

The Sinus of Maier is a slight diverticulum from the upper part of the sac behind the middle of the lateral surface into which the canaliculi open either together or separately

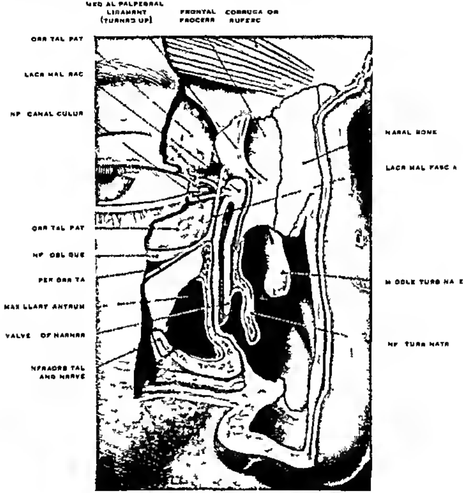


FIG 114 —DISSECTION TO SHOW THE RELATIONS OF THE LACRIMAL SAC AND THE NASO LACRIMAL DUCT FROM IN FRONT
(*Author's preparation*)

THE NASO LACRIMAL DUCT

The naso lacrimal duct, the continuation downwards of the lacrimal sac extending from the so called neck to the inferior meatus of the nose, is only $\frac{5}{8}$ in in length It lies in a canal formed mainly by a groove on the maxilla

(Figs 3 and 6) and completed by the lacrimal bone and the lacrimal process of the inferior turbinate It passes backwards outwards and downwards its direction being given by a line from the inner angle of the eye to the 1st upper molar of the same side

The position and shape of the inferior orifice vary greatly In some cases, where it corresponds to the opening of the bony canal at the highest part of the meatus it tends to be round, in others it runs as a *membranous* tube for some distance under the mucous membrane and is then found at different points down

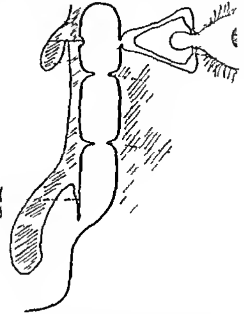


FIG 115 —SCHEME OF THE SO CALLED VALVES OF THE NASO LACRIMAL CANAL
(From Poirier after Aubaret)

the lateral wall of the meatus becoming more slit like as it descends It may be very difficult to find

The naso lacrimal duct is in relation medially with the middle meatus (Fig 114) and laterally makes a ridge in the forepart of the maxillary antrum (Fig 15) *a relation which explains why epiphora is such a frequent symptom of growths of this sinus*

The Valves —Numerous so called valves have been described in the nasal duct They are simply folds of mucous membrane which have no valvular function since fluids can be blown up the duct to come out at the puncta The most constant of these folds is the valve of Hasner (plica lacrimalis) at the lower end which represents the remains of the fœtal septum (see also Fig 114)

Structure —The lacrimal sac and duct are lined by two layers of columnar epithelium which is said to be ciliated in places Mucous glands have also been described In the submucous layer are lymphocytes which may be aggregated into follicles (? pathological) The actual membranous wall of the sac consists

of fibro elastic tissue The naso lacrimal duct is curious in having a rich plexus of veins around it, forming an erectile tissue resembling in structure that on the inferior turbinate bone *Engorgement of these vessels is in itself sufficient to obstruct the duct* (Fuchs)

Whilst at its upper part the naso lacrimal duct can easily be separated from the bone, below it is closely adherent, forming a muco periosteum, and *thus disease may pass easily from bone to duct or vice versa*

Vessels —The *arterial* supply comes from the superior and inferior palpebral branches of the ophthalmic (Fig 142), from the angular artery, from the infra orbital artery, and from the nasal branch of the spheno palatine

The Veins above drain into the angular and infraorbital veins, while below they run into the nasal veins

The Lymphatics pass to the submaxillary the retro pharyngeal, and deep cervical glands

The Nerves —The nerve supply of sac and duct comes from the infratrochlear and anterior superior alveolar

There is probably a reflex relation between the nerve supply of the lacrimal gland and sac, for extirpation of the latter greatly diminishes the tear flow

The Conduction of the Tears

The tears formed by the lacrimal gland are secreted into the outer part of the upper fornix From here they flow over the eye Part of the tears evaporate the rest pass to the lacus lacrimalis probably by the contraction of the orbicularis, which, being more fixed on its inner side, tends to draw the outer part towards the nose (*massage action of the orbicularis*)

Now we must consider how the tears

(*a*) Get into the lacrimal sac.

(*b*) Are discharged into the nose

The tears get into the canaliculi partly through capillarity, partly through the canaliculi becoming shorter and wider during contraction of the orbicularis (Halben)

The orbicularis is attached to the internal palpebral ligament, and this is attached to the sac Hence, when the orbicularis contracts, the ligament is pulled upon and the lacrimal *sac is dilated and so sucks in the tears*

Similarly, Horner's muscle is attached to the fascia covering the posterior part of the sac, and when it contracts will also dilate the sac We must, however add here that some hold that Horner's muscle has the opposite action namely, that it compresses the sac to *expel* the tears

The tears are expelled from the sac by its own elasticity Hence, in those pathological cases in which the lacrimal sac has lost its elasticity (atony of the sac), the downward conduction of tears is arrested, although the nasal duct is quite patent (Fuchs)

The tears pass into the nasal duct rather than into the canaliculi, because the former has a wider calibre, and moreover the downward direction is helped by gravity

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CHAPTER IV

NORMAL APPEARANCES AS SEEN WITH THE SLIT-LAMP AND CORNEAL MICROSCOPE

THE CONJUNCTIVA

The Bulbar Conjunctiva shows itself as a *transparent membrane in which the most striking feature is the vessels*

These form a superficial bright red anastomosing system which is easily distinguished from *the more deeply placed reddish blue episcleral vessels* The superficial vessels move with the conjunctiva, which occurs normally with each blinking movement of the lids

Usually it is impossible to distinguish arteries and veins

Visible streaming of the blood in the vessels can easily be made out Usually the blood current has a somewhat granular appearance But in the smallest vessels, especially at the loops, the blood *column is not infrequently broken up, and one sees* clumps of red cells or even individual cells moving in a somewhat staccato manner

At the limbus the conjunctiva passes over into the transparent cornea without a *sharp line of demarcation*

The Palpebral Conjunctiva—seen by everting the lids—is smooth and transparent, and the chorion presents a rich vascular network, in which one can distinguish *a fine subepithelial plexus and larger vessels running at right angles* to the lid margin, which are derived from the tarsal arches

THE CORNEA

When the slit lamp beam passes through the cornea it forms a characteristic prism, or more correctly a parallelopiped

In this we recognise *four surfaces*

The anterior, corresponding to the epithelium , *the posterior*, corresponding to the endothelium , and the *lateral surfaces*, which form the areas where illuminated and *non illuminated portions of the cornea meet*

With a certain incidence the light may be reflected from the anterior and posterior surfaces of the cornea with mirror-like brightness, and give rise to what are called the anterior and posterior *zones of specular reflection*

The Anterior Surface appears smooth, translucent, and on it can be seen tears and mucus

The Stroma appears somewhat milky, and has a faintly reticular structure, which Koeppe holds is due to lymphatics, a view which cannot be upheld

The Posterior Endothelium can be seen quite clearly (in the posterior zone of specular reflection).

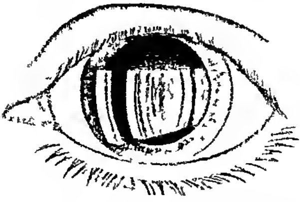

FIG 116—OPTICAL SECTION OF THE EYE AS PRODUCED BY A MODERATE BEAM OF THE SLIT LAMP

The various portions are represented as being in focus simultaneously To the left is the optical section of the cornea then comes a dark interval representing the aqueous next is the optical section of the lens with its bands of discontinuity and Y sutures, behind this the retro lental space is represented dark while the vitreous is most posterior

The cells appear slightly yellow in colour They are mostly hexagonal, some times pentagonal, rarely square and form a mosaic Sometimes their nuclei may be visible

FIG 117—THE CORNEAL PRISM (PARALLELOPIPED)

The light is coming from the left In the anterior zone of specular reflection are tears and mucus in the posterior zone one sees the endothelium and Hassall Henle bodies (seen as black spots)

(Modified from Vogt)

Near the limbus dark areas are seen in the mosaic These are probably due to the (Hassall-Henle) warts on Descemet's membrane

Bowman's and Descemet's membranes are normally not seen, but become visible when pathologically altered

The Line of Turck is a vertical line seen in children from 7 to 16 years old, and due to a deposit of leucocytes at the back of the cornea

The Limbus appears as a transitional zone and has a dentate border Its limits are not so well defined with the slit lamp as with the naked eye

Here we find vascular loops placed between the brilliant tongue shaped prolongations of the sclera

The blood vessels which come from the conjunctiva and sclera have their connecting loops at the limits of the transparent area

Veins and arteries are distinguished with difficulty The colour does not help much Usually one can decide by the direction of the

blood current But even this may be misleading For the current in a certain vessel may be at times towards the cornea at others away from it

Sometimes a *palisade appearance* which is due to whitish tracts derived from the sclera is seen at the limbus more frequently at its upper and lower parts

The Corneal Nerves are easily seen They are most numerous in the middle and anterior layers of the cornea They appear as about thirty whitish filaments which are better marked near the limbus where they still have their myelin sheath The myelin always disappears before the first division of the nerve which is usually dichotomous The nerves never anastomose Not infrequently they present small nodosities usually at a bifurcation which Koeppe holds are congenital neuro fibromata

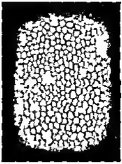

Fig 118 The Endothelium at the back of the Cornea

(*After Vogt*)

The Anterior Chamber

The anterior chamber is almost but not quite optically empty With the ordinary broad slit lamp beam it appears quite black but with a very bright narrow pencil of light especially if oscillating a faint relucence along the path of light can be made out (the aqueous flare) (Graves)

This is due to the fact that the normal aqueous contains very small particles

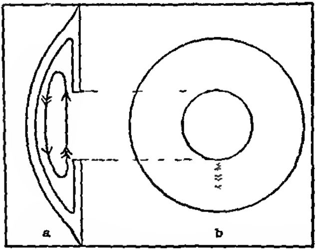

Fig 119 — Diagram showing the Thermic Circulation of the Aqueous Humour

On the left (a) sagittal section of the anterior chamber on the right (b) frontal view In b is seen the line formed by microscopic deposits on the posterior surface of the cornea

(*From Koby*)

which are not big enough to be resolved by the magnification used When larger particles are present they are lit up like dust particles in a beam of sunlight passing across a darkened room

Convection Currents —The cornea is cooled by the air The aqueous therefore behind the cornea is cooler than the aqueous in front of the iris Convection

currents are thus set up, the aqueous sinking behind the cornea and rising in front of the iris. Particles in the aqueous will follow these convection currents, which are no doubt responsible for the line of Turck (see Fig. 119).

The Iris

Embryologically and for descriptive purposes we may divide the iris into three layers: two anterior, which are mesodermal in origin, and a posterior, the retinal portion, which is ectodermal (Fig. 120).

The structure of the iris is seen to differ widely in normal people, and this is essentially dependent on the amount of stroma pigment.

The superficial layers of the blue iris which contains very little stroma pigment appear as a delicate diaphanous tissue, the fibres and trabeculæ of which look

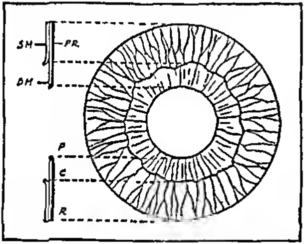

Fig. 120.—Diagram showing the Structure of the Iris.

The retinal layer appears at the edge of the pupil, where it forms the pigment border. The mesodermic layer is separable into a deep layer running from the root of the iris to the pupil and a superficial, the axial limit of which forms the collarette. SM = superficial mesodermic layer. DM = deep mesodermic layer. PR = posterior retinal layer. The crypts of the iris situated in the ciliary portion may be considered as openings distributed in the superficial mesodermic layer (anterior). P = pigment border. C = collarette. R = root of iris. (*From Koby.*)

like transparent wool (Koby). The dark iris presents a more compact structure on which the vessels are not visible except at the crypts. The surface is smooth, and resembles tinder.

Usually clumps of chromatophores producing yellow or brown patches can be seen; but the structure of individual pigment cells cannot be made out with the slit lamp in the human.

The superficial mesodermal layer is shorter than the deep, and extends from the ciliary border to the *collarette* (circulus minor), which forms a dentate fringe, separated from the underlying middle layer of the iris to a varying degree.

It is this superficial layer which gives the ciliary portion of the iris its colour. In it one finds the iris crypts, and looking through these and the underlying deep mesodermal layer one can, in slightly pigmented irides, see the dark posterior ectodermal layer. This latter becomes more and more difficult to see as the amount of stroma pigment increases.

The crypts are bounded by the trabeculæ of the collarette, which are the

remains of obliterated vessels that passed to the papillary membrane during embryonic life (Lauber and Vogt)

The Deep Mesodermal Layer extends from the ciliary border to the pupillary edge

In slightly pigmented irides it has a radial fibrillary appearance and is transparent, so that the deeply pigmented ectodermal layer is visible through it

The Collarette (circulus minor) consists of a series of trabeculæ forming a rough and broken circle, and varies greatly in form To it are often attached remains of the pupillary membrane

The anterior mesodermal layer is but loosely attached to the deeper one and glides freely over it It does not participate to any marked extent in the movements of the rest of the iris It thus comes about that as the pupil dilates

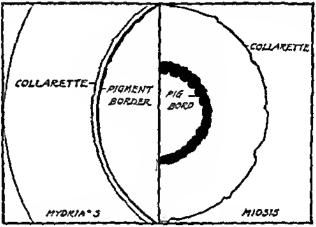

FIG 121 —DIAGRAM SHOWING THE RELATIONS OF THE PIGMENT BORDER AND COLLARETTE AND THE VARIATIONS IN THICKNESS OF THE FORMER ACCORDING TO THE WIDTH OF THE PUPIL

To the left pupil dilated to the right pupil contracted

(*From Koby*)

the pupillary edge approaches nearer and nearer to the collarette—so when the pupil is widely dilated remains of the pupillary membrane may appear to arise from the edge of the pupil when they are actually attached to the collarette

There are other changes as the pupil dilates

The pigment ring showing at the pupillary border is thinned and may disappear

There is a much more decided step between the collarette whose angles have straightened out and the pupillary margin the crypts become oblique clefts The vessels are more tortuous the contraction furrows and the peripheral furrows are deeper and the border zone disappears

The vessels of the iris can be made out in non or very slightly pigmented irides The radial vessels can be seen passing to the collarette and then following one of its trabeculæ

They do *not* form a complete circle Hence *circulus* iridis minor is not strictly correct

The Sphincter Iridis can be seen if the iris contains little or a moderate amount of pigment

The Ectodermal Layer, as pointed out above, can be seen through the crypts in slightly pigmented irides. Its edge is seen at the pupillary border as a fringe of pigment with a crenated margin. This is much better marked when the pupil is small, especially above. The slightest pupillary reaction is made manifest with the slit lamp.

The dilatator pupillæ and the nerves of the iris are invisible.

The Lens

When the beam of the slit lamp passes through the lens it is obvious that the portion lit up (the optical section) is not homogeneous. It is divided into a number of bands, some of which are brighter than others. These bands are called by Vogt the zones of discontinuity (Fig. 116). In adults ten bands can usually be made out.

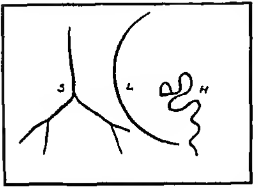

FIG. 122.—DIAGRAM SHOWING THE RELATION OF THE POSTERIOR ⅄ OF THE FŒTAL NUCLEUS (S) OF THE ARCUATE LINE (L) OF THE INSERTION OF THE REMAINS OF THE HYALOID ARTERY (H) IN A RIGHT EYE. (*From Koby.*)

The artery is found on the nasal side separated from the posterior pole of the lens by the arcuate line, the concavity of which is turned towards the artery.

Of these, the anterior and posterior bands (of the lens) corresponding to the anterior and posterior surfaces of the lens, are the brightest.

The Fœtal Nucleus, which represents the condition at birth, appears as two plano-convex lenses with a central dark interval which is the most homogeneous portion of the lens and the part which has the least optical density.

In front and behind the fœtal nucleus are the *anterior and posterior Y shaped sutures*.

The anterior Y is upright, the posterior is inverted (⅄) contrary to the usual anatomical description.

The farther we go from the fœtal nucleus, the more complicated do the sutures become.

Around the fœtal nucleus are the *anterior* and *posterior peripheral bands* of the fœtal nucleus. More peripheral still are *the anterior and posterior bands of the adult nucleus*, while beneath the anterior and posterior bands of the lens are the *subcapsular bands* or anterior and posterior bands of disjunction (Vogt).

The Anterior Surface of the lens does not appear homogeneous, but is somewhat irregular, and gives an appearance resembling shagreen (anterior lens shagreen).

At the *Posterior Surface* of the lens, as well as the anterior, there is a zone where the light is reflected vividly (*zones of specular reflection*).

In the posterior zone of specular reflection is seen the *Posterior Lens Shagreen*.

It has a slightly yellower tint than the anterior A marked polychromatic lustre in the posterior region is diagnostic of a complicated cataract

A corkscrew like *remainder of the* ***Hyaloid Artery*** which moves with the movements of the eye is often seen fixed by a whitish dot to the posterior aspect of the lens just below and internal to its centre and in the concavity of the arcuate line (Fig 122)

The Arcuate Line is a whitish crescent situated below and internal to the posterior pole of the lens It is found by tracing the nasal branch of posterior λ till it bifurcates

The Suspensory Ligament of the lens cannot be seen in the normal eye When the lens is congenitally dislocated or absent it may be made out as consisting of cobweb like strands which are attached in front and behind the equator

Fig 123 —The Normal Vitreous Body of a Subject of Twenty Years the Light coming from the Left

On the left is seen the posterior band of the lens where the zone of specular reflection has been avoided On its right the vertical bundles of the vitreous, and a second system of bundles chiefly horizontal and finer Magnification about × 30 *Figure slightly schematic*

(From Koby)

The Remains of the Pupillary Membrane

1 The commonest form consists of a series of brown dots on the anterior capsule of the lens usually near the centre which when seen with the slit lamp have a stellate appearance These are finer than the remains of posterior synechia which also when present in any quantity tend to be disposed in a circle

2 Fine filaments arising from the collarette and branching in the anterior chamber are attached to the front of the lens where they may end in white tufts or pass across the anterior chamber and be attached to another part of the collarette

3 Thick cord like *remains* which are usually associated with anterior polar cataract

The Vitreous

Only the anterior third of the vitreous can be seen with the slit lamp as ordinarily used

Directly behind the posterior band of the lens is the post lenticular space This with the ordinary broad beam of the slit lamp appears optically empty i e quite black (Fig 116) The less the illumination the deeper does the space

appear On the other hand with higher intensities of illumination faint fibrils can be seen crossing this space

Comberg believes that the space is capillary only No hyaloid membrane can be made out with the slit lamp

[1] The anterior part of the vitreous appears as wavy milky folds of gossamer like texture separated by intervals which are optically empty—the whole oscillating with the movements of the eye The folds appear to consist of criss crossing fibrils Small nodosities may be seen at the intersection of two fibrillæ

In old age a powdery appearance in the vitreous is quite common

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Other Standard works by

- Meesman 1927
- Lemoine and Valois 1931
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[1] For the probable explanation of the slit lamp appearances of the vitreous see p 11"

CHAPTER V

THE EXTRINSIC MUSCLES OF THE EYE

THE *extrinsic* muscles of the eye are so called to distinguish them from the muscles inside the globe, the dilatator and sphincter pupillæ and the ciliary muscle, which are unstriped and named *intrinsic*

The extrinsic muscles of the eye are six in number, the superior, inferior, medial and lateral recti, and the superior and inferior obliques In the case of the superior and external recti the fleshy portions end in a V, while in the inferior and internal they end in a dentate line

The insertions into the sclera are made by glistening tendons whose fibres run almost entirely parallel to the long axis of the muscle These fibres consist of fibrous tissue supported by thick elastic fibres Apart from their size they resemble the scleral fibres, being made of the same tissue But whereas the tendon fibres are practically all longitudinal, the scleral fibres run in many directions (Fig 30) This results in the tendon having a glistening silky appearance while the sclera is dull white (Salzmann)

The tendon fibres enter the superficial layers of the sclera, and soon become indistinguishable from it (Fig 30) Only the cessation of the thick elastic fibres marks the place where one begins and the other ends

Not infrequently one finds fibres which leave the main tendon close to its insertion to be attached farther back These recurrent fibres may be missed in doing a tenotomy (Motais)

Structure of the Extrinsic Muscles.—These muscles, as are all those derived from the branchial arches, are more highly differentiated than any other muscles of the body

Instead of being grouped together in bundles separated by dense connective tissue, the fine fibres are but loosely united and hence easily separated by dissection

In the intervals between the fibres are a great number of nerve fibres It must be remembered that each eye muscle receives a nerve which is relatively, compared with the size of the muscle it supplies, much bigger than any in the body

Each muscle fibre has a diameter of 15 9 22 7 μ, thus being less than other striate muscles Each fibre is surrounded by a sarcolemma which contains a granular sarcoplasm in which myofibrils may be seen This gives the cross section of the fibril a punctiform appearance Directly under the sarcolemma are one or more well staining nuclei

The connective tissue around the fibres constitutes the endomysium and

contains a large quantity of elastic tissue arranged longitudinally Similar septa but surrounding a number of muscle fibres are called the internal perimysium This contains larger elastic fibres the vessels and nerves and some connective tissue cells The internal perimysium is continuous with the external perimysium which surrounds the muscle

The muscles of the eye are peculiar in the number of nerve and elastic fibres which they contain Schifferdecker believes that the elastic tissue helps the muscle in action and regulates the give of its antagonist This contributes to the making of the delicacy and smoothness of ocular movements

The Sheaths of the Muscles—From the origin for two centimetres the sheath is practically non existent being very thin and transparent so that the macro scopic structure of the muscle is easily visible From the level of the back of the globe it becomes thicker opaque and disposed in two layers the outer or orbital layer with circular fibres and the inner with longitudinal fibres The inner is continuous with the internal perimysium

The Actions of the Eye Muscles

Movements of the eyeball take place round the centre of movement which corresponds approximately to the centre of the eye The eyeball as a whole therefore is not displaced

The movements may be resolved into those taking place round the three *primary axes* which pass through the centre of the movement and are at right angles to each other These are

(1) The *vertical* axis round which the centre of the cornea moves outwards (abduction) or inwards (adduction)

(2) The *transverse* axis runs from right to left Round it the centre of the cornea moves either up (elevation) or down (depression)

(3) The *sagittal* or antero posterior axis corresponds to the line of vision Round it the movement of wheel rotation takes place and is called inwards (intorsion) or outwards (extorsion) as twelve o clock on the cornea moves nasally or temporally It will thus be seen that in naming the movements of the eye about the transverse and vertical axes the centre of the cornea (or the pupil) is taken as the moving point and will indicate in which direction the eye is made to look while *wheel rotation* about the antero posterior axis is named from the direction of movement of the upper part of the vertical meridian or what comes to the same thing twelve o clock on the cornea

This is a necessary convention for it is obvious that the posterior pole of the eye will go up when the anterior goes down and the lower part of the vertical meridian (or six o clock on the cornea) will move out when the upper moves inwards

Each muscle except the internal and external recti has a *main* and a *subsidiary* action

The main action will be greatest when the eye is looking in a certain direction, while in this position the subsidiary actions will be least and vice versa.

Thus the main action of the superior rectus will be elevation, and is greatest when the eye is turned out, while the subsidiary actions adduction and wheel-rotation inwards are increased as the eye looks inwards.

Synergic Action.—Often in carrying out a certain movement two muscles work together. Thus, in looking directly upwards the superior rectus will act with the inferior oblique, and in looking directly downwards the inferior rectus acts with the superior oblique.

The Four Recti Muscles

The four recti muscles arise from a short funnel shaped tendinous ring

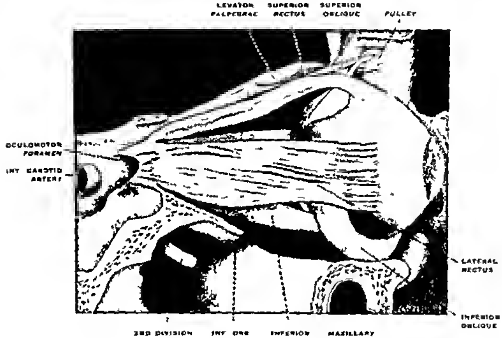


Fig 124.—Dissection to show the Ocular Muscles from the Lateral Aspect
Note especially oculo motor foramen
(*From a specimen in the Anatomy Museum of University College*)

(annulus tendineus communis of Zinn). This is oval on cross-section, and encloses the optic foramen and a part of the medial end of the superior orbital (sphenoidal) fissure, its attachment to the anterior margin of which is marked by the *spina recti lateralis*

The inner surface of the annulus is thickened in its upper and lower parts by two strong bands or *common tendons*.

The Lower Tendon (of Zinn) is attached to the inferior root of the small wing of the sphenoid between the optic foramen and the sphenoidal fissure. This attach-

ment may be marked by a tubercle (the infraoptic tubercle) (Fig 1) a roughness or a small depression The lower tendon gives origin to part of the internal and external recti and the whole of the inferior

The Upper Tendon (of Lockwood) arises from the body of the sphenoid and gives origin to part of the internal and external recti and the whole of the superior

Owing to the slope of the orbital roof the origin of the superior and internal recti are on a plane anterior to the others *Also[1] these muscles are much more closely related to the dural sheath of the optic nerve*

With regard to their *length* which is somewhere about 40 mm the superior is the longest then the medial then the lateral The inferior is the shortest

The recti muscles run forwards close to the walls of the orbit and are inserted into the sclera by tendons of different widths and at different distances from the cornea

These will be discussed with each muscle and will be found tabulated below

	Distance from Cornea	Length of Tendon	Width of Tendon
	mm	mm	mm
Superior rectus	7 7	5 8	10 8
Inferior rectus	6 [illegible]	5 5	9 8
Internal rectus	6 [illegible]	8 8	10 3
External rectus	6 9	3 7	9 2

The Superior Rectus

The superior rectus arises from the upper part of the annulus of Zinn above and to the outer side of the optic foramen and from the sheath of the optic nerve

This origin lies in the angle formed by the splitting of the dura which lines the optic canal to form the orbital periosteum (periorbita) on the one hand and the dural covering of the nerve on the other

It is below that of the levator and is continuous on the inner side with the medial rectus and on the outer with the lateral rectus

The muscle passes forwards and outwards beneath the levator, making an angle of 25° with the visual line pierces Tenon's capsule and is inserted into the sclera 7 7 mm from the cornea by a tendon 5 8 mm long

The line of insertion is oblique 10 8 mm long and curved so as to be slightly convex forwards

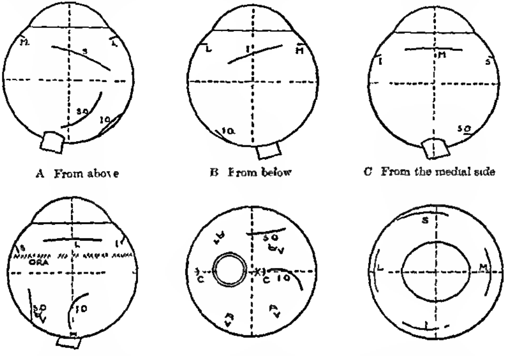
Relations — *Above* the superior rectus is in relation with the levator and the frontal nerve which separate it from the roof of the orbit (Figs 143 and 144)

Below is the optic nerve but separated by orbital fat, the ophthalmic artery, and the naso-ciliary nerve (Fig 145) Farther forwards the reflected tendon of the superior oblique passes between it and the globe to reach its insertion (Fig 124)

[1] It is this attachment of the superior and internal recti to the nerve sheath which is responsible for the characteristic pain which accompanies extreme movements of the globe in retrobulbar neuritis

Laterally, in the angle between the superior and lateral recti, are found the lacrimal artery and nerve

Medially, in the angle between the superior rectus on the one hand and the medial rectus and superior oblique on the other, are found the ophthalmic artery and nasal nerve (Figs 144, 145)



A From above B From below C From the medial side

D From the lateral side E From behind F From in front

FIG 125—TO SHOW THE INSERTIONS OF THE EYE MUSCLES

λ = position of the macula C = long ciliaries V = venæ vorticosæ S O = superior oblique I O = inferior oblique M = medial rectus L = lateral rectus I = inferior rectus S = superior rectus

Note position of optic nerve Its centre is just *above* the horizontal meridian

Nerve.—The superior rectus is supplied by the superior division of the oculomotor (3rd cranial), which enters the under surface of the muscle at the junction of the middle and posterior thirds (Fig 147).

Actions.—The superior rectus makes the eye look upwards and inwards and also wheel rotates it inwards (intorts) It also helps[1] the levator to lift the upper lid

The Main Action is the elevation, which increases as the eye is turned out, and becomes nil when the eye is turned in

The superior rectus is, in fact, the only elevator in the abducted position of the eye, for the inferior oblique does not elevate the eye in this position It thus

[1] See p 184

comes about that in a palsy of the right superior rectus, if the patient is asked to look upwards and to the right, he cannot elevate his right eye beyond the middle of the palpebral fissure

The subsidiary actions are the adduction and intorsion, which increase as the eye is turned in

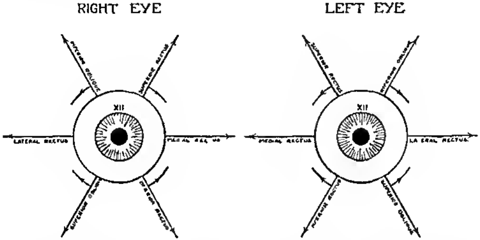


FIG 126 —DIAGRAM TO SHOW THE ACTION OF THE EXTRINSIC MUSCLES OF THE EYES

The straight arrows show the direction in which the eye is made to look i e towards which the centre of the cornea is moved The small curved arrows indicate the direction of wheel rotation i e about an antero posterior axis Thus the medial and lateral recti make the eye look inwards and outwards respectively, while the superior oblique makes the eye look downwards and outwards and at the same time causes wheel rotation inwards (taking XII o clock as the moving point)

THE INFERIOR RECTUS

The inferior rectus is the shortest of the recti muscles It arises below the optic foramen from the middle slip of the lower common tendon

It passes forwards and somewhat outwards along the floor of the orbit, making an angle of 25° with the visual line and is inserted into the sclerotic 6 5 mm from the cornea by a tendon 5 5 mm in length

The line of insertion is 9 8 mm long markedly convex forwards, always somewhat oblique, so that the nasal end lies nearer the cornea

The inferior rectus is also attached to the lower lid by means of the fascial expansion of its sheath (see Fig 146 and p 186)

Relations —*Above* are the inferior division of the 3rd nerve, the optic nerve separated by orbital fat, and the globe of the eye (Fig 146)

Lateral —The nerve to the inferior oblique runs in front of the lateral border of the inferior rectus or between it and the lateral rectus

Below is the floor of the orbit roofing the antrum of Highmore The muscle is in contact with the orbital process of the palate bone, but more anteriorly it is separated by orbital fat from the orbital plate of the superior maxilla

The infraorbital vessels and nerve in their canal also lie below the inferior rectus

The inferior oblique crosses below the inferior rectus the sheaths of the two muscles being united here

Nerve —The inferior rectus is supplied by the inferior division of the 3rd nerve which enters it on its upper aspect at about *the junction of the middle and posterior thirds* (Figs 146 and 147)

Its **Blood-supply** comes from the inferior muscular branch of the ophthalmic

Actions —The inferior rectus makes the eye look down and in and also wheel rotates it outwards (extorsion) By means of its fascial expansion it also depresses the lower lid (see p 186)

The Main Action is the depression[1] which increases as the eye is turned out and becomes nil when the eye is turned in

The Subsidiary Actions are the adduction and extorsion which increase as the eye is turned in

The Medial Rectus

The medial rectus is the largest of the ocular muscles and much stronger than the lateral It has a wide origin to the inner side of and below the optic foramen from both parts of the common tendon and from the sheath of the optic nerve

It passes forwards along the medial wall of the orbit and is inserted into the sclerotic 5 5 mm from the cornea by a tendon 8 8 mm in length The line of insertion is 10 3 mm long is straight and symmetrical to the horizontal meridian (as a rule)

Relations — *Above* is the superior oblique and between the two muscles are the ophthalmic artery and its anterior and posterior ethmoidal branches and the nasal nerve (Figs 144 145)

Below is the floor of the orbit

Medially is some peripheral orbital fat then the lamina papyracea of the ethmoid which bounds the ethmoidal air cells

Laterally is the central orbital fat

Nerve —The inferior division of the 3rd which enters it on its lateral surface *at about the junction of its middle and posterior thirds*

The **Blood-supply** comes from the inferior muscular branch of the ophthalmic artery

Action —The internal rectus is a pure adductor Both muscles act together in convergence

The Lateral or External Rectus

The lateral or external rectus arises from both the lower and upper parts of the common tendon from those portions which bridge the superior orbital (sphenoidal) fissure

[1] The inferior rectus is the only depressor in the abducted position of the eye

This origin is continuous and is strengthened by its attachment to the spina recti lateralis (of Merkel) on the great wing of the sphenoid

The origin thus takes the form of the letter U (or V) placed so that the opening looks towards the optic foramen, the limbs of the U being referred to as the *upper* and *lower heads* of the muscle (Figs 124 and 133)

The lateral rectus passes forward along the lateral wall of the orbit at first separated only by a small and variable amount of peripheral fat More anteriorly however, it passes inwards towards the globe pierces Tenon s capsule and is inserted into the sclera 6 9 mm from the cornea by a tendon 3 7 mm long

The line of insertion is 9 2 mm in length is vertical or slightly convex forwards and usually symmetrical

The external rectus can in the living often be seen through the conjunctiva and Tenon s capsule (see also paragraph on the expansions of its sheath p 186)

Relations —(*a*) *At the Apex of the Orbit* —Between the origin of the external rectus and that portion of the small wing which separates the optic nerve from the medial portion of the superior orbital (sphenoidal) fissure is a small though very important interval

The structures which go through it are described as passing between the two heads of the lateral rectus within the cone of muscles or annulus of Zinn or the interval is called the *oculomotor* foramen (Fig 124)

These structures from above downwards are the *upper division* of the *3rd nerve*, the *naso ciliary* and a branch from the *sympathetic* then the *lower division* of the *3rd* then the *6th* and then sometimes the *ophthalmic vein* or veins

The 6th nerve is actually passing from being below the lower division of the 3rd to lie lateral and in between the two divisions (Fig 133)

Above the cone of muscles i e above the upper head of the lateral rectus are the *fourth frontal* and *lacrimal nerves* the *recurrent lacrimal artery*, and the *superior ophthalmic vein* According to Hovelacque (1927) these structures do not pass through the outer narrow part of the sphenoidal fissure as is classically represented since this is closed by dense fibrous tissue and with this the author is in entire agreement (See also the lacrimal nerve p 210) Below the cone of muscles nothing passes as a rule sometimes the inferior ophthalmic vein

(*b*) *Further Forwards* —*Above* the lateral rectus are the lacrimal artery and nerve The lacrimal gland lies anteriorly The lacrimal nerve is in relation to the upper border for almost its whole length the artery only for the anterior two thirds

Below is the floor of the orbit, and anteriorly the tendon of the inferior oblique passes below then medial to the lateral rectus to gain its insertion (Fig 124)

Medial near the apex of the orbit between the lateral rectus and optic nerve are the ciliary ganglion and ophthalmic artery Between the muscle and the inferior rectus is the nerve to the inferior oblique (Figs 145 146) Laterally it lies directly against periorbita in its posterior part while more anteriorly a slight

amount of perimuscular fat intervenes, farther forward still the lacrimal gland lies between it and the bone

Nerve.—The 6th nerve (abducens) enters it on its medial aspect, just behind its middle

The **Blood-supply** comes from the lacrimal artery

Actions.—The external rectus is a pure abductor—that is, makes the eye look directly outwards

The Superior Oblique

The superior oblique is the longest and thinnest eye muscle It arises by a narrow tendon above and medial to the optic foramen, which partially overlaps the origin of the levator

The fusiform muscle belly, more rounded than that of the other extrinsic muscles, passes forwards between the roof and medial walls of the orbit to the pulley or trochlea of the superior oblique (Figs 124 142 144)

The trochlea consists of a U shaped piece of fibro-cartilage, which is closed above by fibrous tissue, and is attached to the fovea or spina trochlearis on the under aspect of the frontal bone a few millimetres behind the orbital margin It is lined by synovial membrane, and from its outer border a strong fibrous sheath accompanies the tendon to the eyeball

The muscle, about 1 cm behind the trochlea gives place to a rounded tendon, which passes through the pulley then bends downwards, backwards, and outwards at an angle of about 55° (the trochlear angle) pierces Tenon's capsule, passes under the superior rectus, and, spreading out in a fan shaped manner, is attached obliquely in the postero superior quadrant almost or entirely lateral to the mid-vertical plane. The line of insertion is about 10 7 mm long, and is convex backwards and laterally Its anterior end lies about on the same meridian as the temporal end of the superior rectus (Salzmann) (see Figs 124 and 125 A)

Actions.—The superior oblique makes the eye look down [1] and out and also (wheel) rotates it inwards (i e makes twelve o'clock on the cornea move towards the nose)

The Main Action is the depression, and this increases as the eye is turned in [2] It is practically nil when the eye is abducted

The abduction and intorsion are the *subsidiary actions*, and increase as the eye turns out

The superior oblique acts with the inferior rectus to make the eye look directly down

Nerve.—The superior oblique is supplied by the 4th or trochlear nerve which, having divided into three or four branches, enters the muscle on the upper surface

[1] It used to be believed that the *superior* obliquus made the eye look up and in, and hence the term "pathetic" applied to its nerve So far as facial expression is concerned the muscle expresses disgust or contempt

[2] The superior oblique is the only muscle which can depress in the adducted position

near its outer border, the most anterior branch at the junction of the posterior and middle thirds, the most posterior about 8 mm from its origin (Fig 144)

The **Blood-supply** comes from the superior muscular branch of the ophthalmic artery

Relations —The superior oblique is in relation with the periosteum of the roof and medial walls of the orbit separated only by a very thin layer of fat or none at all Below it is the medial rectus and between the two muscles are the ophthalmic artery and its ethmoidal branches and the nasal nerve In the interval between the superior oblique and the levator posteriorly is the fourth nerve while anteriorly are the supratrochlear nerve accompanied by the frontal artery and tributaries of the superior ophthalmic vein (Fig 144)

The reflected tendon is in relation above with the supratrochlear and medial branch of the supraorbital nerve and with the supraorbital vessels (Fig 144) Also the levator covers this surface and then bends round it to become more or less vertical while the superior rectus covers the tendon at its insertion

The deep surface is in relation to orbital fat then Tenon's capsule and the globe.

The Inferior Oblique

The inferior oblique is the only extrinsic muscle to take origin from the front of the orbit, it is also remarkable in having the shortest tendon of insertion (Figs 36 142 147)

It arises by a rounded tendon from a small depression (sometimes a roughness) on the orbital plate of the superior maxilla a little behind the lower orbital margin and just external to the orifice of the naso lacrimal duct Some of its fibres may, in fact arise from the fascia covering the lacrimal sac

It passes outwards and backwards, making an angle of 50° with the visual line (that is parallel with the reflected tendon of the superior oblique) between the inferior rectus and the floor of the orbit then under the external rectus to be inserted by a very short tendon[1] (Fig 36) (often none at all) to the back and outer portion of the globe for the most part below the horizontal meridian The line of insertion is oblique 9 4 mm long and is convex upwards

Its posterior or nasal end is about 5 mm from the optic nerve *and thus lies practically over the macula* (only 2 2 mm from it (Poirier)) (Fig 125 E) The anterior, temporal end lies in about the same meridian as the lower end of the insertion of the lateral rectus

Relations —Near its origin the lower surface of the muscle is in contact with

[1] As Salzmann points out one often finds actual muscle fibres inserted into the sclera The shortness of the tendon of the inferior oblique may be used to determine to which side an excised globe belongs Having found it we know which is the upper and which is the lower aspect of the globe The attached tendons of the obliques will point away from the side to which it belongs

the periosteum of the floor of the orbit but further laterally, it is separated from this by fat. Just before the insertion of the muscle this surface which now faces laterally is covered by the external rectus and the capsule of Tenon.

The upper aspect is in relation to fat then the inferior rectus then finally spreading out and becoming concave it moulds itself on the globe.

Nerve.—The inferior oblique is supplied by the inferior division of the oculo motor, which crosses above the posterior border about its middle to enter the muscle on its *upper*[1] surface.

The **Blood-supply** comes from the infraorbital artery and the inferior muscular branch of the ophthalmic.

Actions.—The inferior oblique makes the eye look up and out, and also wheel rotates it outwards (extorts).

The Main Action is the elevation which increases as the eye is turned in[2] and is nil in abduction.

The Subsidiary Actions are the abduction and extorsion, which increase as the eye is turned out.

The inferior oblique acts with the superior rectus to make the eye look directly upwards.

The Levator Palpebrae Superioris

The levator palpebrae superioris arises from the under surface of the lesser wing of the sphenoid above and in front of the optic foramen by a short tendon which is blended with the underlying origin of the superior rectus.

The flat ribbon like muscle belly passes forwards below the roof of the orbit and on the superior rectus to about 1 cm. behind the septum orbitale (that is more or less at the upper fornix or a few millimetres in front of the equator of the globe) where it ends in a membranous expansion or *aponeurosis*. This spreads out in a fan shaped manner so as to occupy the whole breadth of the orbit and thus gives the whole muscle the form of an isosceles triangle. The fleshy part of the muscle is horizontal the tendinous part is nearly vertical moulding itself on the globe of the eye as indeed does the whole of the upper eyelid. The change of direction takes place round the reflected tendon of the superior oblique.

Attachments.—(*a*) The main insertion of the levator is to the *skin* of the upper lid at and below the upper palpebral sulcus. It reaches this by passing through the fibres of the orbicularis (Fig. 99).

(*b*) *To the Tarsal Plate*.—Some of the fibres of the aponeurosis are attached to the front[3] and lower part of the tarsal plate, but the main attachment of the levator here is via the unstriped *superior palpebral muscle*. This is continuous

[1] Usually described as entering the posterior border. In the above description which I have verified I am following Hovelacque.

[2] The inferior oblique is the only elevator in the adducted position.

[3] The fibres of the levator form a definite layer here *which it is important to realise especially in exposing the tarsal plate from in front*.

with the fleshy part of the levator and is attached to the upper border of the tarsus (Figs 99 and 100)

(c) The attachment of the levator to the superior fornix of the *conjunctiva* is actually via the fascial sheath of the muscle (see later)

(d) The two extremities of the aponeurosis are called its ' *horns* ' The *lateral horn* passes between the orbital and palpebral portions of the lacrimal gland (Fig 140) which is as it were folded round it and is attached to the orbital tubercle and to the upper aspect of the lateral palpebral ligament (Fig 142)

The *medial horn* is much weaker than the lateral It is attached somewhat below the fronto lacrimal suture and to the medial palpebral ligament

The Sheath of the levator has several points of interest It is attached below to that of the superior rectus (*q v*) and it is the tissue between the two muscles which gains attachment to the upper conjunctival fornix (Fig 106) On the upper aspect of the junction of aponeurosis and muscle the sheath is thickened to form a band (Whitnall) the medial end of which passes up to the pulley of the superior oblique and to the neighbouring bone and sends a slip to bridge over the supraorbital notch The lateral end of the band passes above the aponeurosis and is in part joined to it Part of it passes into the lacrimal gland and part reaches the lateral orbital wall Whitnall considers these the true check ligaments of the levator

Relations —*Above* the levator and between it and the roof of the orbit are the 4th and frontal nerves and the supraorbital vessels The 4th nerve crosses the muscle close to its origin from without inwards to reach the superior oblique (Fig 144)

The supraorbital artery is above the muscle in its anterior half only

The frontal nerve crosses the muscle obliquely from the lateral to the medial side

Below the levator is the inner part of the superior rectus (which being the larger muscle has its lateral edge exposed) and the globe of the eye (Fig 144)

In front of the tendon at its commencement is the retro septal roll of fat which is continuous with the upper and inner orbital lobe of fat Below this the front of the tendon of the levator is in relation with the septum Behind is the pre tarsal space containing the peripheral palpebral arcade (Fig 99) and the palpebral portion of the lacrimal gland The pretarsal space (see p 126) placed behind the tarsal insertion of the tendon is prolonged laterally behind the outer horn of the levator and contains here the palpebral portion of the lacrimal gland

Nerves —(*a*) The *Superior Division of the 3rd* which reaches the muscle either by piercing the medial edge of the superior rectus (and thus forming another bond between the two muscles) or by winding round its medial border

(*b*) *Sympathetic Fibres* to the unstriped superior palpebral muscle

Action —The levator raises the upper eyelid thus uncovering the cornea and a portion of the sclera and deepens the superior palpebral fold Its antagonist is the orbicularis

The Capsule of Tenon

The capsule of Tenon (fascia bulbi) is a thin fibrous membrane which envelops the globe from the margin of the cornea to the optic nerve

Its inner surface is well defined and in close contact with the sclera to which it is connected by fine trabeculæ

These opposing surfaces were held by Schwalbe to be lined by endothelium the capsule of Tenon thus forming an articular socket in which the eyeball moves

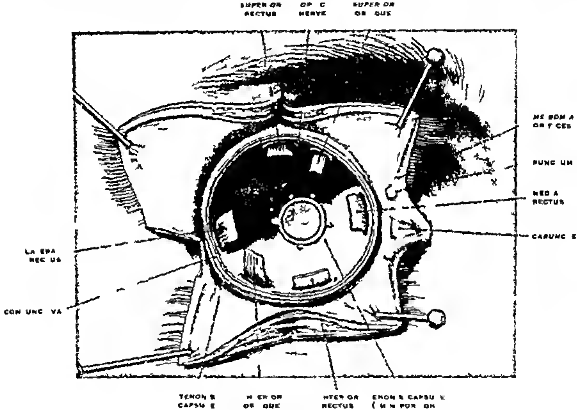


Fig 117—Dissection to show Tenon's Capsule

The (right) eye has been removed
(Author's preparation)

freely in all directions The joint cavity too was thought by Schwalbe to be a lymph space continuous behind with the lymph space surrounding the external coat of the optic nerve (supravaginal lymph space) But the capsule of Tenon is attached to the globe in front to the ocular muscles and to the sclera by the above mentioned trabeculæ It is probable therefore that while slight movements take place between the globe and the capsule in more extensive movements the globe and the capsule move together in the surrounding fat

The posterior surface of Tenon's capsule is in contact with the orbital fat from which it is separated with difficulty

Anteriorly the fascia bulbi becomes thinner and merges gradually into the subconjunctival connective tissue It is separated from the conjunctiva by loose connective tissue and in operations for exposing the ocular muscles can always be demonstrated separately from this membrane

Posteriorly around the optic nerve where it is pierced by the ciliary vessels and nerves it becomes very thin and can only be traced with difficulty to the dural sheath of the optic nerve with which it is held to be continuous Schwalbe however describes it as being continuous with a membrane which surrounds this sheath to form the supravaginal lymph space—a view which is now held to be very doubtful

The lower part of the capsule of Tenon is thickened to form a sling or hammock on which the globe rests and which has received the name of the *ligament of Lockwood* That it is effective in supporting the eye is shown by the fact that the globe does not sink down after removal of the superior maxilla

Tenon's Capsule is pierced posteriorly by the optic nerve (Fig 127) and around this by the ciliary nerves and arteries just behind the equator by the venæ vorticosæ and anteriorly by the six extrinsic muscles of the eye

Where the fascia bulbi is pierced by the tendons of the extrinsic muscles it sends round each *a tubular reflection* backwards which clothes it like the fingers of a glove

The *reflections* differ in the different muscles

In the case of the recti they gradually become continuous with the perimysium but send important slips or expansions to surrounding structures

The lateral expansion of the external rectus is attached to the orbital tubercle on the malar bone while that of the internal rectus passes to the lacrimal bone

These expansions are strong and to some extent limit the action of the muscles They have therefore received the name of *check ligaments*

The expansion of the superior rectus is attached to the levator palpebræ by a definite band in which a bursa may be found (Motais) This band is important physiologically It ensures the synergic action of the two muscles Thus when the superior rectus makes the eye look upwards the upper lid is raised as well

The expansion from the inferior rectus (Fig 148) passes from the under surface of this muscle above the inferior oblique then deep to the conjunctival cul de sac and the palpebral conjunctiva from which it is separated by the unstriped inferior palpebral muscle (which according to Fuchs can be seen through the conjunctiva), and then is inserted between the tarsal plate and the orbicularis By this means the inferior rectus can act on the lower lid as the levator acts on the upper The lower lid is in fact lowered 2 mm and pulled down by its action and the lashes tend to be everted This movement is however aided by the lid being in contact with the globe

The reflection of the superior oblique passes up to its pulley that of the inferior oblique to the outer part of the floor of the orbit

From the anterior end of the expansions of all the muscles fibrous bands pass

to be attached to the conjunctival cul de sac When the muscles act the conjunctiva is pulled back also, and thus is prevented from folding and strangulation, much in fact as the musculus articularis genu pulls the synovial membrane of the knee joint out of the way in contraction of the quadriceps and prevents it being nipped by the patella.

Practical Considerations

From a practical point of view there are four spaces which we must consider inside the orbit

(1) Firstly, and *most important*, is that bounded in great part by the rigid orbital walls, but, anteriorly, by the eye and septum orbitale including the tarsal plates and tarsal ligaments

(2) Since the periorbita is for the most part easily detachable there is a potential space between it and the bone

(3) Inside this is the space bounded by the cone of muscles, the intermuscular membrane and the capsule of Tenon

The *intermuscular membrane* is described by *Poirier* as follows "*The sheaths of the four recti muscles are joined to each other by an aponeurotic membrane, which becomes thinner as we trace it backwards and anteriorly is continuous with the capsule of Tenon It is strongest between the superior and external recti muscles In thin and feeble subjects it may be ill marked, and hence is neither mentioned nor figured by many authors* At the posterior pole of the eye it separates the fat of the orbit into two layers one central the other peripheral, and controls to a certain extent the progress of infiltrations"

From the above it follows that the *muscle cone forms a separate space* Hence an exploration of the orbit outside it can have but little effect on a lesion situated within it This is illustrated by a case described by Harrison Butler The orbit was explored several times in a patient with proptosis and rigors and no pus was found Later, on removal of the eye, *the pus was found inside the muscle cone*

(4) The fourth space to be considered is Tenon's capsule, and Harrison Butler and others have recorded cases where a conjunctival incision has been effective in evacuating pus from this space

The methods, then, that might be employed to relieve tension in the orbit are

(*a*) An incision into the orbit outside the muscle cone

(*b*) An incision into the orbit with splitting of the lid in a vertical direction and division of one or both tarsal ligaments This was the method used by *George Lawson and Tweedy*

(*c*) The division of one or other ocular muscle This not only allows the eye to move farther forwards and so diminishes the pressure behind it, but also opens up the muscle cone and Tenon s capsule, and gives a good view of the back of the eye and anterior part of the optic nerve

(*d*) Opening Tenon's capsule by a conjunctival incision

(*e*) Temporary resection of part of the orbital wall as in Kronlein s operation

The Orbital Fat

The orbital fat fills in all the intervals not occupied by the other structures It is probably semi fluid during life, and, as stated above, may be divided into *central* inside the cone of muscles and intermuscular membrane, and *peripheral* between these and the periorbita The slits between the lobules were regarded by Hirschfeld (1909) as lymphatic spaces, but actually no real lymphatics have

as yet been demonstrated in the orbit If the lids including the septum orbitale be removed, the capsule of Tenon and the expansion of the sheaths of the muscles form an incomplete barrier between the orbital fat and the lids It is through the holes in this partial barrier that the fat of the orbit can escape to produce the characteristic swellings under the skin of the lids The most common hernia of the orbital fat thus produced is in the upper and inner quadrant

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CHAPTER VI

THE NERVES

The Oculo Motor or 3rd Cranial Nerve

Superficial Origin —The oculo motor nerve arises by a series of 10 to 15 rootlets for the most part from the sulcus oculo motorius, which lies on the inner side of the crus cerebri A small external portion however, actually takes origin from

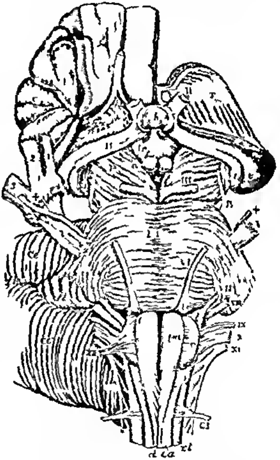


Fig 128 —Ventral Aspect of the Brain stem showing the Attachments of the Principal Cranial Nerves

The following references apply to the roots of the nerves I = right olfactory tract divided near its middle II = left optic nerve springing from the commissure which is concealed by the pituitary body II right optic tract the left tract is seen passing back into *i* and *e* the internal and external corpora geniculata *III* = left oculo motor nerve IV trochlear V,V large roots of the trifacial nerves + + = small roots the + of the right side is placed on the Casserian ganglion 1 = ophthalmic 2 = superior maxillary and 3 = inferior maxillary nerves VI = left abducent nerve VII = facial VIII = auditory IX glosso pharyngeal X = pneumo gastric XI = spinal accessory XII = right hypo glossal nerve at *o* on the left side the rootlets are seen cut short C1 = suboccipital or first cervical nerve

(After Allen Thomson in Quain's "Anatomy")

the neighbouring ventral surface of the crus As pointed out by Zander, the two portions almost meet posteriorly, but separate anteriorly and so practically form a letter V

The posterior part of this origin comes close to the upper border of the pons and is a near relation of the termination of the basilar artery (Figs 174 175)

Between the two nerves is the posterior perforated substance

The posterior cerebral artery runs along the inner side of the origin of the 3rd nerve, then curls round above the upper rootlets (Figs 174 and 175) It often sends twigs between the rootlets of the nerve The superior cerebellar artery runs below the origin at the upper border of the pons (Figs 130, 175)

Course and Relations—(*a*) *In the Posterior Cranial Fossa*—Surrounded by pia and bathed in cerebro spinal fluid the 3rd nerve passes downwards and

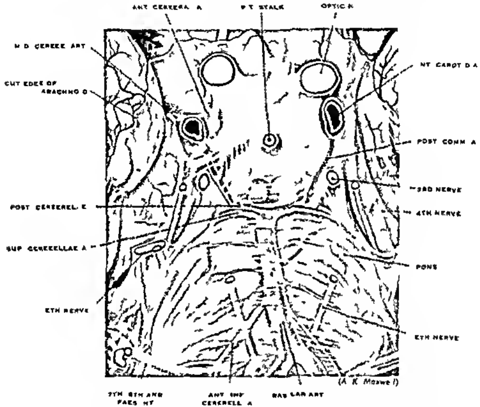


Fig 129—The Cisterna Basalis and Cisterna Pontis

A portion of the base of the brain with the arachnoid in situ showing the relation of this membrane to the cranial nerves (II to VIII) and to the circle of Willis

forwards in the cisterna basalis[1] (Fig 129) between the posterior cerebral and superior cerebellar arteries (Figs 130 131 142)

At first somewhat flattened in form it twists on itself so that the inferior fibres become superior and leaving the arteries, soon becomes a rounded cord,

It runs above and medial to the free margin of the tentorium cerebelli and

[1] The cisterna basalis is the large subarachnoid space which is formed by the bridging across of the temporal lobes by arachnoid It contains the crura the interpeduncular space and the circle of Willis

4th nerve, and below and lateral to the posterior communicating artery (Fig. 130). *It crosses the under-aspect of the optic tract from within outwards* (Fig. 132).

For about 1 cm., i.e. from a point just behind the posterior clinoid

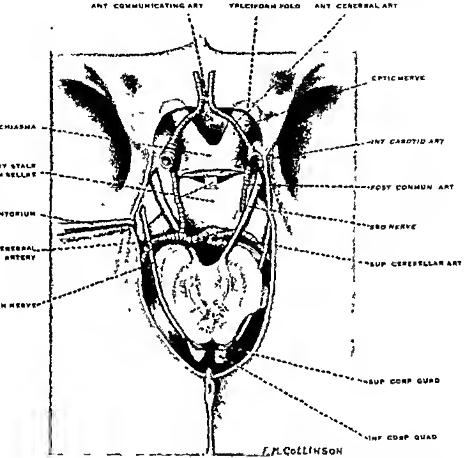


Fig 130.—Dissection to show the Course of the 3rd and 4th Nerves and the Relation of the Circle of Willis to the Pituitary Fossa

The mid brain is divided in the aperture of the tentorium, and the cerebrum removed. On the right side the posterior cerebral and posterior communicating arteries are cut short *in order to expose the origin of the 3rd nerve.* On the left side the tentorium and crus cerebri are slightly separated so as to show the 4th nerve more fully.

(Somewhat after T. W. P. Lawrence in Quain's "Anatomy")

process to the point where the nerve pierces the dura, it is surrounded by arachnoid.

(*b*) *In the Middle Cranial Fossa.*—The 3rd nerve passes just lateral to the posterior clinoid process and above the attached margin of the tentorium cerebelli It now lies lateral to the pituitary fossa *above* the cavernous sinus; then, piercing the dura about midway between the anterior and posterior clinoid processes close

to the prolongation forwards of the free margin of the tentorium cerebelli it comes to lie in the lateral wall of the sinus (Figs 131 138 139)

Here it has the 4th nerve and the first and second divisions of the 5th nerve

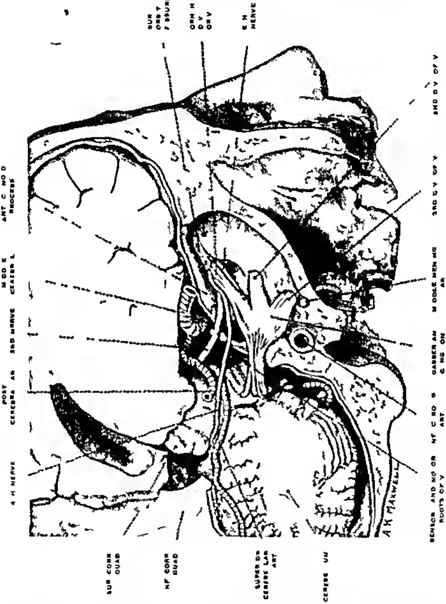


FIG 131 —DISSECTION TO S[illegible] THE INTRACRANIAL COURSE OF THE 3RD 4TH AND 6TH NERVES

below and lateral in that order from above downwards and the 6th nerve and internal carotid artery actually in the sinus lying below and medial to it

While in the lateral wall of the sinus the 3rd nerve receives communications from the first division of the 5th and the sympathetic round the carotid artery

The 3rd nerve now enters the superior orbital (sphenoidal) fissure, but just before it does so it divides into a small superior and a larger inferior division, and about at this point the 4th nerve[1] crosses the 3rd to lie above and then medial to it

At the anterior part of the cavernous sinus, too, the ophthalmic division of the 5th crosses the 3rd from below upwards, and just about this point divides into its three branches

(c) *In the Superior Orbital (Sphenoidal) Fissure*.—The two divisions of the 3rd nerve pass through the fissure within the annulus of Zinn, i e between the two heads of the lateral rectus (Fig 133) They have the naso ciliary nerve medial and between them, and the 6th nerve at first below, then lateral The fourth, frontal and lacrimal nerves pass through the *wide* portion of the fissure above the annulus

(d) *In the Orbit*.—*The superior division* passes inwards above the optic nerve and just behind the naso ciliary to supply the superior rectus on its undersurface at the junction of the middle and posterior thirds (Figs 145, 146, 147), and the levator palpebræ superioris The branch to the latter muscle either pierces or curls round the medial border of the superior rectus

The inferior division, much larger than the superior, sends branches to the internal rectus, the inferior rectus, and the inferior oblique

The branch to the internal rectus passes under the optic nerve to enter the muscle on its *lateral* or ocular aspect near the junction of its middle and posterior thirds (Fig 147)

The branch to the inferior rectus pierces the muscle on its upper aspect near the junction of middle and posterior thirds

The long branch to the inferior oblique runs along the floor of the orbit on the lateral border of the inferior rectus or between this muscle and the external rectus It crosses[2] above the posterior border of the inferior oblique about its middle, and breaks up into two or three branches which enter the *upper* surface of the *muscle*

It is this nerve that gives the short stout branch to the ciliary ganglion, which eventually supplies the sphincter pupillæ and the ciliary muscle.

Communications and Varieties.—(*a*) A branch of communication from the 6th to the 3rd in the lateral wall of the cavernous sinus has been described, but must be very rare

(*b*) The superior division fairly often has a communicating branch from the nasal (Testut)

[1] *The position of this crossing is variable Testut holds that at the level of the optic foramen the 4th and 5th nerves are still below and lateral to the 3rd*

[2] *The nerve is usually described as entering the posterior border of the muscle* A careful dissection will, however, show that it continues on as described above

(c) Volkmann describes a twig from the 3rd to the superior oblique

(d) Generali describes a case where a branch from the 3rd replaced the 6th which was absent

(e) Henle in one case saw the branch to the inferior oblique pierce the inferior rectus and the same branch was seen by Arnold to pass through the lower part of ciliary ganglion (Quain)

(f) There may be no short branch to the ciliary ganglion which then sits directly on the nerve to the inferior oblique (Testut)

Summary of the Oculo motor Nerve

The superior branch supplies
- Superior rectus
- Levator palpebræ superioris

The inferior branch supplies
- Internal rectus
- Inferior rectus
- Inferior oblique
- Short branch to the ciliary ganglion

As a whole, the 3rd nerve supplies all the extrinsic muscles of the eye except the external rectus and superior oblique and also innervates the sphincter pupillæ and the ciliary muscle

Nucleus and Connections (see also p 359)

Each 3rd nerve nucleus forms a small column of multipolar nerve cells some 10 mm long which lies in the floor of the aqueduct of Sylvius beneath the superior corpus quadrigeminum Its superior extremity reaches to the floor of the third ventricle while it ends below on a level with the border of the superior colliculus

The nuclei of opposite sides are separated above by 2 to 3 mm, but come together below

The dorso medial aspect of each nucleus is in relation with the grey matter of the aqueduct, its infero lateral with the posterior longitudinal bundle (Fig 135) Inferiorly the third nucleus is continuous with that of the fourth

Localisation within the Nuclei—The two third nuclei taken as a whole, consist of five parts two *main lateral* nuclei, an unpaired central *nucleus of Perlia* which unites the main nuclei and the paired small celled *nucleus of Edinger Westphal* situated anteriorly (Fig 136)

The Main Lateral Nuclei contain the centres for the motor nerves to the eye muscles Each muscle is governed by a well defined group of cells These from before backwards are *probably* levator palpebræ superior rectus inferior oblique,

inferior rectus The centre for the internal rectus (inward movement) is next to the median nucleus of Perlia

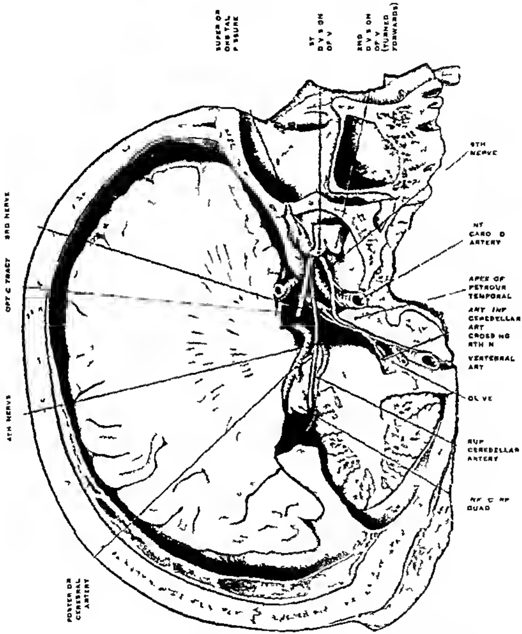


Fig 132—Dissection to illustrate the Bend in the Course of the 6th Cranial Nerve (Author's preparation)

The Central Nucleus of Perlia [1] probably has to do with convergence Thus convergence and inward movement, whose centres lie close together, although often affected together, are not necessarily so

[1] Perlia *Arch f Ophth* 1889 xxxv (4) p 287

The Nucleus of[1] *Edinger-Westphal*[2] probably subserves the pupillary musculature

The fibres from the anterior part of the third nucleus are direct, i e go to the muscles of the same side , of those from the posterior part some are held to be direct and some crossed

From the nucleus the axones of the 3rd nerve pass through the posterior longitudinal bundle, the tegmentum, the red nucleus, and the medial margin of substantia nigra, to emerge from the sulcus oculo motorius on the medial aspect of the crus (Figs 130 and 135) The bundles corresponding to the various muscles remain separate in the mid brain and for a little distance beyond the superficial origin of the nerve

Connections —The third nucleus receives fibres from the superior quadrigeminal bodies, the occipital cortex, the frontal cortex of the opposite side, and the cerebellum via the superior peduncle It sends fibres via the posterior longitudinal bundle to the 4th and 6th nerves of the same and opposite sides, and some which join the 7th, and are said eventually to supply the orbicularis oculi and frontalis Hence these muscles escape in a supranuclear lesion of the facial

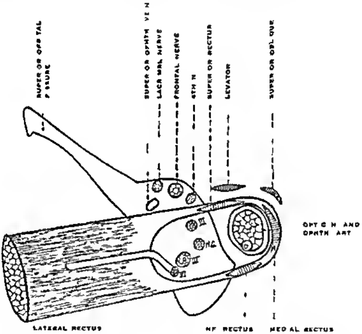


FIG 133 —DIAGRAM OF THE STRUCTURES PASSING THROUGH THE SUPERIOR ORBITAL FISSURE AND OPTIC FORAMEN (L W)

III — upper and lower divisions of the 3rd nerve N C = Naso ciliary VI = 6th nerve

Structure of the 3rd Nerve.—Like the 6th and 4th, the 3rd nerve is very

[1] Edinger (a) *Arch f d ie ges Physiologie,* 1885 xxi p 858, (b) *Untersuchungen über d vgl Anat des Gehirns,* (c) *Vorlesung,* 1911

[2] Westphal, *Centralbl f Nervenheil* 1889

large compared with the muscles it supplies It contains about 15 000 fibres Most of them are large but some destined for the ciliary ganglion are small Most of the fibres are motor, but some are sensory Of the latter, some are derived from the 5th nerve, but others are proprioceptive, and can be demonstrated in the orbit, i e distal to the point where the branch of the trigeminal joins the 3rd (Sherrington and Tozer 1910)

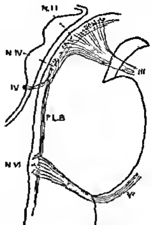


Fig 134 —Plan of the Origins of the 3rd 4th and 6th Nerves

The nerves and their nuclei are projected into the outline of a median section of the mid brain and pons III 3rd nerve N III = its nucleus IV = 4th nerve N IV = its nucleus P L B posterior longitudinal bundle VI = 6th nerve N VI = its nucleus

(From Quain s Anatomy)

The non medullated fibres in the nerve were regarded by Boeke (1915, 1921) as sympathetic, but Woollard and others hold that they are proprioceptive in function and pass up in the mesencephalic root of V

Practical Considerations

1 *Paralysis of the 3rd nerve results in the following*

(*a*) Ptosis from paralysis of the levator

(*b*) The eye looks outwards and downwards due to the overaction of the external rectus and superior oblique, and there is inability to look upwards, downwards, or inwards

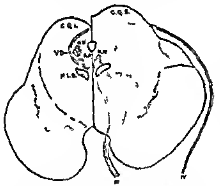


Fig 133 —Plan of the Origins of the 3rd and 4th Nerves

The mid brain is supposed to be divided at different levels on the two sides the section on the right side of the figure passing through the superior and on the left side through the inferior quadrigeminal body III = 3rd nerve N III = its nucleus IV = 4th nerve N IV = its nucleus V D = descending or mesencephalic root of the 5th nerve N V = its nucleus C Q S = superior and C Q L = inferior quadrigeminal body P L B = posterior longitudinal bundle

(From Thane in Quain s Anatomy)

(*c*) There is wheel rotation inwards on asking the patient to follow the examining finger downwards and outwards (overaction of the superior oblique)

(*d*) The pupil is semi-dilated, and does not react to light or accommodation

(*e*) Sometimes slight proptosis

(*f*) As the strabismus is divergent the diplopia is crossed , on looking up the false image will be higher than the true , on looking down the false image will be lower than the true, and inclined towards it from wheel rotation of the superior oblique

2 *The Syndrome of Weber* consists of a 3rd nerve palsy on the side of the lesion with a facial paralysis and hemiplegia of

the opposite side. The facial palsy is of the upper motor neurone type, the upper part of the face being spared. The syndrome is due to a mid brain lesion and involves the seventh fibres and those of the trunk and limbs before their crossing.

The Syndrome of Benedikt is like that of Weber, but the hemiplegia is associated with tremors. These are due to involvement of the red nucleus.

3. It is of interest to note that the 3rd and 4th nerves are more commonly affected by pituitary enlargements than that *enfant chétif* of the cerebral contents, namely the 6th, which is here protected by the internal carotid. A glance at Fig. 132 will explain this.

4. The 3rd nerve may be pressed on by hardening or an aneurism of any of the arteries with which it is in close relation, namely the posterior cerebral, superior cerebellar, basilar, posterior communicating and internal carotid.

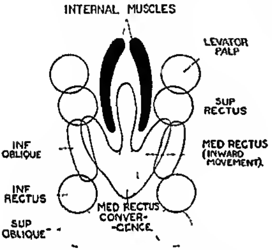


Fig. 136.—Scheme of the 3rd Nerve Nuclei.

The portion that supplies the internal muscles is the nucleus of Edinger Westphal. The median nucleus (of convergence) is the nucleus of Perlia.
(*After Brouwer and Zeeman.*)

THE 4TH CRANIAL OR TROCHLEAR NERVE

The trochlear is the most slender of the cranial nerves and yet has the longest intracranial course (75 mm.).

Superficial Origin (Fig. 137).—After having crossed[1] from the opposite side in the valve of Vieussens (anterior medullary velum) which forms part of the roof of the 4th ventricle, the trochlear nerve leaves the anterior part of this membrane by two or three rootlets medial to the superior cerebellar peduncle and just behind the posterior corpus quadrigeminum. Its attachment to the valve is very slight and the smallest pull will often detach it from its origin.

It is the only motor nerve, cranial or spinal, which arises from the dorsal aspect of the central nervous system.

Relations.—(*a*) *In the Posterior Cranial Fossa*.—Surrounded by pia and bathed in cerebro spinal fluid the nerve passes at first laterally behind the superior cerebellar peduncle. In this part of its course it is crossed from below upwards by the branch of the superior cerebellar artery to the inferior corpus quadrigeminum. It now runs forwards at the upper border of the pons between and parallel to the posterior cerebral and superior cerebellar arteries (Figs. 131 and 132). It

[1] See also p. 3 9.

appears on the ventral aspect of the brain between the temporal lobe and the pons (Fig 129) At first medial and below the free margin of the tentorium cerebelli, the 4th nerve soon comes to lie beneath and to be hidden by this membrane (Fig 130)

The 5th nerve which takes origin from the lateral aspect of the pons just above its middle passes forwards below and lateral to the 4th (Fig 131)

The 3rd nerve is above and medial, but since its direction is downwards and

FIG 137 —DISSECTION TO SHOW THE ORIGIN OF THE 4TH NERVE
(Author's preparation)

forwards and that of the 4th almost directly forwards, they approach each other as they proceed anteriorly, and as we shall see, eventually cross (Figs 130, 131, 132)

Just before entering the middle cranial fossa by passing lateral to the dorsum sellæ and while still under cover of the free margin of the tentorium cerebelli the 4th nerve acquires a very short covering of arachnoid which it loses again where it pierces the dura

(b) *In the Middle Cranial Fossa* —The trochlear nerve pierces the dura in the

lateral angle between the free and attached margins of the tentorium cerebelli, and then lies in the lateral wall of the cavernous sinus above and medial to the Gasserian ganglion and lateral to the pituitary fossa (Figs 131 132, 139)

Here the 3rd nerve is at first above and medial, but just before it enters the superior orbital (sphenoidal) fissure the 4th nerve crosses it so as to be at first lateral then above, then medial

The first and second divisions of the 5th are below and lateral and in the sinus itself the 6th nerve and internal carotid artery are below and medial

(c) *In the Superior Orbital (Sphenoidal) Fissure* —The 4th nerve enters the orbit through the *wide* portion of the superior orbital (sphenoidal) fissure close to its upper border above the cone of muscles with the frontal and lacrimal nerves which are lateral to it and the ophthalmic vein which is below it (Figs 133 and 139)

The 3rd naso-ciliary and the 6th nerves and sometimes the ophthalmic vein pass through the fissure within the annulus of Zinn

(d) *In the Orbit* the 4th nerve leaves the frontal nerve which is at first close to it at an acute angle and passes inwards and forwards beneath the periorbita (periosteum) (Fig 143) and above the levator and superior rectus (Fig 144) It divides up in a fan shaped manner into three or four branches which supply the *superior*[1] *oblique* on its upper (or inner) surface near the outer (or upper) border, the most anterior branch entering the muscle at the junction of the posterior and middle thirds and the most posterior some 8 millimetres beyond its origin

Nucleus and Connections

The 4th nerve nucleus lies in the dorsal part of the cerebral peduncle deep to the upper part of the inferior colliculus ventro lateral to the aqueduct of Sylvius and dorso medial to the posterior longitudinal bundle with which it is in very close relation (Figs 134 135)

Like the 3rd nerve nucleus which is continuous with it above it represents the upward continuation of the base of the anterior horn of the spinal cord

It consists of multipolar nerve cells some 40 to 50 μ in diameter

From the nucleus the fourth fibres run first outwards to reach the medial surface of the mesencephalic root of V, then downwards parallel to the aqueduct, then at the lower border of the inferior colliculus they pass inwards to decussate completely (or almost so) in the anterior medullary velum The fourth nerve thus crosses to the opposite side and each superior oblique is supplied from the opposite fourth nucleus The fibres emerge at the medial border of the brachium conjunctivum

The connections are similar to those of the 3rd nerve

Communications and Varieties

1 While in the outer wall of the cavernous sinus the 4th nerve is connected with the

[1] See footnote p 181

sympathetic on the carotid artery, and is joined by a filament probably containing proprioceptive fibres from the ophthalmic division of V

2 In one case the 4th nerve pierced the levator on its way to the superior oblique (Thane)

3 The nerve has been observed in several cases sending a branch forward to the orbicularis palpebrarum or to join the supratrochlear, the infratrochlear, or the nasal nerve (Thane)

4 A communication with the frontal nerve is recorded by Berte (Thane)

Structure.—The 4th nerve consists of about 1,200 fibres, mostly of large size It also shows close to its origin the vestiges of a degenerated ganglion (Gaskell) See also structure of the 3rd nerve

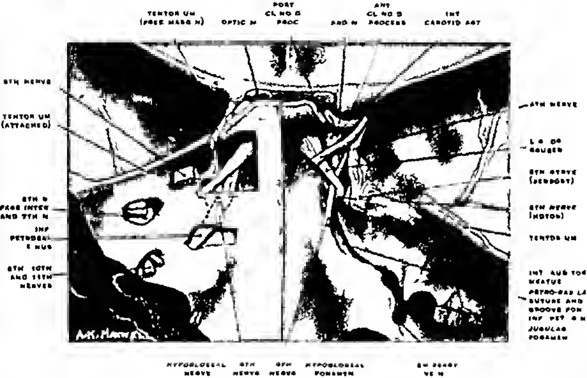


Fig 138 Dissection to show Relations of 6th Nerve to the Petrous Temporal, Inferior Petrosal Sinus, etc

On the right side the dura has been removed to show the bony relations

(Author's dissection)

Practical Considerations

Paralysis of the 4th nerve produces palsy of the superior oblique This results in

(a) The greatest limitation of movement is seen when in the adducted position the patient is asked to look downwards This is because the superior oblique is only depressor in the adducted position

(b) The face is turned downwards and towards the sound side

(c) Diplopia occurs on looking downwards, and is homonymous

The false image is below, and its upper end is tilted towards the true image, i e in the direction of action of the paralysed muscle

The Abducens or 6th Cranial Nerve

Superficial Origin.—The 6th cranial nerve emerges between the lower border of the pons and the lateral part of the pyramid by seven or eight rootlets, some of which may actually pierce the pons

Course.—It passes upwards forwards, and slightly outwards in the posterior cranial fossa to pierce the dura over the basiocciput, then runs upwards under this membrane on the back of the petrous temporal near its apex, then forwards through the cavernous sinus Finally it passes into the orbit through the superior orbital fissure within the annulus of Zinn to supply the external rectus muscle

Relations.—(*a*) *At its Origin*—The two 6th nerves are about 1 cm apart at their superficial origin, and between them lies the basilar artery at its formation from the two vertebrals Sometimes an asymmetrical vertebral artery may curve upwards and lie under the nerve The origin of the 7th nerve to the outer side of the olive is lateral (Figs 128 174)

(*b*) *In the Posterior Cranial Fossa*—The nerve, at first flat and fasciculated, soon becomes rounded and firmer Covered by pia it passes upwards, forwards, and slightly outwards in the cisterna pontis of the subarachnoid space (Fig 129) between the pons and the occipital bone (Fig 132) After a course of 15 mm it pierces the dura at the back of the basilar portion of the occipital bone about 2 cm [1] below and slightly to the outer side of the posterior clinoid process, and just to the inner side of or posterior to the inferior petrosal sinus which lies in the petro basilar suture (Fig 138)

It is plastered to the pons by the arachnoid (Fig 129) but does not receive a complete covering of this membrane till a few millimetres from the dural opening (Figs 132, 174, 175)

Just beyond its origin it is crossed by the antero inferior cerebellar artery Usually, i e in over four fifths [2] of the cases, the artery is ventral but it may be dorsal or pass between the rootlets of the nerves The 3rd, 4th and 5th nerves are above, but are gradually approaching the 6th as they pass forwards towards the middle cranial fossa

Under the dura the 6th nerve crosses the inferior petrosal sinus from within outwards, and runs almost vertically up the back of the petrous temporal near its apex It is placed and held here in a groove [3] (which may be quite well marked, though not infrequently difficult to find) Having arrived at the sharp upper

[1] The spheno basilar suture is about 1·5 cm from the top of the dorsum sellæ (H A Harris) Hence the 6th nerve pierces the dura opposite the occipital bone

[2] Stopford J S B *Journ of Anat and Phys*, 1915–16, l, and 1916 17 li

[3] Hovelacque, *Nerfs Craniens*, p 108

border of the bone, it bends[1] forwards practically at a right angle under the petro sphenoidal ligament of Gruber, and under the superior petrosal sinus to enter the cavernous sinus (Figs 132 138) The abducens nerve and the inferior petrosal sinus enter the sinus together by an opening which is known as Dorello's canal (Fig 138)

(c) *In the Cavernous Sinus*.—In the cavernous sinus the 6th nerve runs almost horizontally forwards In the posterior part of the sinus the nerve winds round the lateral aspect of the ascending portion of the internal carotid artery,

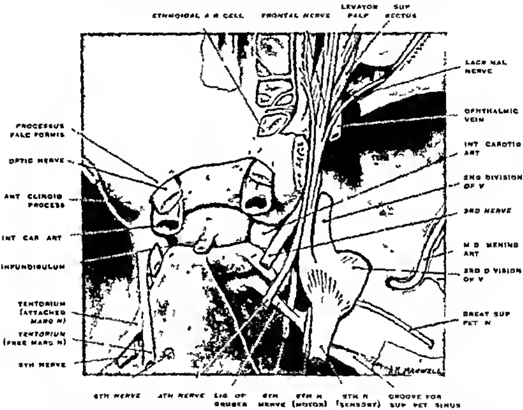


Fig 139.—Dissection to show Nerves passing from Middle Cranial Fossa into Orbit (Author's preparation)

thus making a *second* bend,[2] this time, however, with its concavity inwards (Fig 138)

Farther forwards the abducens lies below and lateral to the horizontal portion of the artery (Figs 132 182)

The carotid is here surrounded by a sympathetic plexus, which sends branches of communication to the 6th nerve (Fig 132)

[1] See Wolff, *Brit Journ Ophth*, Jan 1925

[2] This second bend varies greatly It may be very slight, the ascending portion of the internal carotid just pushing the nerve slightly laterally or it may (as the author saw in one case) approach the right angle

In the lateral wall of the sinus from above down are the third fourth and first and second divisions of the 5th nerve (Fig 182)

Usually the 6th nerve lies actually in the sinus surrounded by a separate sheath, but it may be adherent to the lateral wall or attached to it by a mesentery

Outside the lateral wall of the sinus is the Gasserian ganglion

(d) *In the Superior Orbital Fissure*—The 6th nerve is placed here within the annulus of Zinn at first below the two divisions of the 3rd nerve, then lateral and in between the two The naso ciliary is medial

(e) *In the Orbit*—The nerve divides into three or four filaments which enter the inner surface of the external rectus muscle just behind its middle

Anastomoses

From (a) *The Sympathetic* in the cavernous sinus (b) *From the Ophthalmic* just before entering the orbit (c) From the *Spheno Palatine Ganglion* (Meckel)

Variations

(a) The 6th nerve may arise in two parts which may remain separate to the superior orbital fissure

(b) The nerve or part of it may pass above the ligament of Gruber

(c) It may give a branch to the ciliary ganglion (Pourfour du Petit)

(d) The nasociliary nerve may be a branch of the 6th (Krause)

(e) The 6th nerve may be absent (Generali) its work being done by the 3rd

Nucleus and Central Connections

The nucleus of the 6th nerve is a small spherical mass consisting of large multipolar cells lying close to the mid line in the tegmental portion of the pons under cover of the *colliculus facialis* This is an elevation in the floor of the fourth ventricle which is produced by the bend of the fibres of the 7th nerve (Figs 137 and 156)

The fibres pass forwards through the whole length of the pons first medial to the superior olive then lateral to the pyramid some fibres passing through the latter (Fig 156)

Connections—Some axones go from the nucleus of the sixth (or as is much more probable from an intercalated neurone in the medial longitudinal bundle) into the medial longitudinal bundle to the 3rd nerve nucleus of the opposite side they are concerned with conjugate movements of the eyes one external rectus working with the internal rectus of the opposite side The following[1] is the probable course of the supranuclear fibres for conjugate movement of the globes Arising from the cortical centres in the frontal lobe the fibres pass in the anterior limb of the internal capsule and occupy a medial position in the crus They cannot be traced farther than the upper part of the pons Varolii, but the probability is that they find their way through the tegmentum to the nucleus of the 6th cranial nerve

[1] Head *Trans Ophth Soc* xviii p 39 Also Allbutt *System of Med* vi p 782

The abducens nucleus is also connected to the superior olive, bringing it into relation with hearing, and to Deiter's nucleus, which makes a communication with the vestibular apparatus

Some Practical Considerations

1 Division of the 6th nerve results in paralysis of the external rectus muscle There is internal strabismus. The eye *can* move to the middle of the palpebral fissure, but no farther The diplopia is homonymous, and is worse on looking outwards

2 Fractures of the base of the skull are very liable to involve the 6th nerve owing to its close relation to the apex of the petrous temporal bone

3 Paralysis of the 6th nerve alone has no localising value The abducens is, in fact, the weakling of the cranial contents, and may be affected in almost any type of cerebral lesion, whether near or *at a distance* from the nerve Many theories have been evoked to account for this

(*a*) Collier[1] thought that it was due to the shifting *backwards* of the brain stem Those nerves whose direction was most nearly fronto-caudal would be involved before the others

Thus the 6th would be the first, then the 3rd, and lastly the 7th and 8th.

But if this were true the frailer 4th nerve, with its longer antero posterior course, ought to be first affected It is suggested that it is protected by the free margin of the tentorium cerebelli, in which it lies for a part of its course, an explanation that will hardly hold for an antero posterior pull ,

(*b*) Cushing[2] showed that the antero inferior cerebellar artery, when it ran ventral to the 6th nerve[3] (a relation present in 86 per cent on the right side and 81 per cent on the left) might, as a result of increased intracranial pressure, press on and groove the nerve and the underlying pons, and thus produce an external rectus palsy.

(*c*) The author[4] suggested that the important factor was the bend over the sharp apex of the petrous temporal. If we consider a tumour in any position in the cranium there will come a time when, owing to the increase of intracranial pressure, the brain will be forced to its largest outlet—the foramen magnum—and foraminal herniation ensue As a result of this the medulla and pons will tend to move *downwards* Now the 6th nerve is fixed to the pons and more or less held in the cavernous sinus It will therefore be pressed against the sharp upper border of the petrous temporal, with resulting interruption of conduction and palsy of the external rectus Blows on the vault of the skull, quite apart from those which are complicated by basal fractures involving the apex of the petrous

[1] Collier, J *Brain* 1904 xxvii p 490
[2] Harvey Cushing *Brain* 1910–11 xxxii
[3] Stopford, see p 202
[4] E Wolff, *Brit Journ. of Ophth*, Jan 1928

temporal, will also tend to force the hind brain downwards, with resulting tension in the 6th nerve. A similar condition of movement towards the foramen magnum will follow compression of the skull in difficult labour with or without forceps, and probably explains the 6th nerve birth palsy.

4. *Gradenigo's Syndrome.*—A palsy of the 6th nerve and severe unilateral headache in suppurative middle-ear disease. The 6th nerve is involved at the

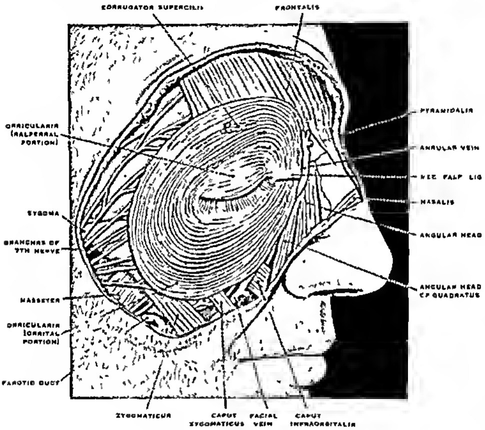


FIG. 140.—DISSECTION OF ORBIT FROM IN FRONT.
Stage I Orbicularis oculi
(*Author's dissection.*)

apex of the petrous temporal by direct spread of infection, usually through a pneumatic condition of the bone.

5 An abducens and facial palsy existing together suggest a lesion of the floor of the 4th ventricle—where the fibres of the seventh have such a close relation to the nucleus of the 6th

The Syndrome of Millard-Gübler consists of a facial and sixth palsy of the same side as the lesion with a hemiplegia of the opposite side The facial

palsy is of the lower motor neurone type, i.e. involves the whole nerve. The syndrome is due to a bulbo pontine lesion.

6. According to Grey, division of the 6th nerve results at times in ptosis and small pupil owing to the sympathetic fibres it contains.

7. Conjugate[1] deviation of the eyes may be due to an *irritative* lesion of the supranuclear fibres, or a *paralytic* lesion of the sixth nucleus[2] or its connection with the 3rd nerve of the opposite side. In the former case the eyes are forcibly turned to one or other side from tonic spasm of the associated muscles, in the latter the patient is unable to turn the eyes to one or other side owing to paralysis of the associated mechanisms.

In a cortical hæmorrhage the eyes look towards the side of the lesion in the brain. In a pontine hæmorrhage involving the nucleus of the 6th the patient cannot look towards the side of the lesion, and often has an associated palsy of the facial nerve of the lower motor neurone type on the same side.

The 5th Cranial or Trigeminal Nerve

The trigeminal, the largest of the cranial nerves, resembles a typical spinal nerve: it has two roots, sensory and motor, and further, on the sensory root, there is a large ganglion.

Superficial Origin.—The two portions of the 5th nerve arise close together somewhat above the middle of the lateral surface of the pons. The sensory portion is much larger than the motor (portio minor), which is placed above and internal to its companion (Figs. 128 and 131).

Course and Relations.—The two portions of the trigeminal pass almost directly forwards, with only a very slight inclination upwards in the posterior cranial fossa towards a notch at the upper border of the petrous temporal, which they reach after a course of about 1 cm. They are surrounded by separate sheaths of pia but enclosed in a common covering of arachnoid which accompanies them to the ganglion. Princeteau has shown that the arachnoid is reflected on to the two roots, but is at first some distance from them, a complete sheath only being formed a few millimetres behind the apex of the petrous temporal. Its relation to the nerve is in fact that of the canvas of a tent to its central pole (Fig. 129).

The facial, auditory and pars intermedia are *below* and diverging towards the internal auditory meatus. *Above* is the cerebellum, the free margin of the tentorium cerebelli, with the 4th nerve close under it.

The 6th nerve, which is at its origin some distance (about $1\frac{1}{2}$ cm.) below and medial to the 5th, gradually approaches it, and comes to lie quite close to its inner side at the apex of the petrous temporal (Fig. 138).

[1] See Head in Allbutt's *System of Medicine*, vi, p. 782.

[2] As stated on p. 204, it is much more probable that the fibres which go to the opposite third nucleus arise not in the sixth nucleus but in an intercalated neurone situated in the medial longitudinal bundle above it.

The 5th nerve pierces[1] the dura under the attached margin of the tentorium cerebelli which contains the superior petrosal sinus, and having spread out in a plexiform manner, joins the posterior concave border of the semilunar (Gasserian) ganglion (Figs 138 139)

The Semilunar (Gasserian) Ganglion is the sensory ganglion of the 5th nerve, corresponding and having a similar structure to the posterior root ganglion of the spinal nerves It is also liable to the same affections[2] It is somewhat

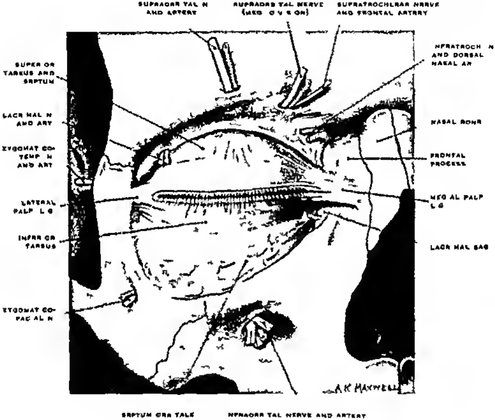


Fig 141 —Dissection of Orbit from in Front
Stage 2 Orbicularis reflected to show septum orbitale
(*Author's dissection*)

crescentic or better, bean shaped in appearance the hilum being directed backwards The ganglion is some 4 cm medial to a point just above the articular tubercle at the root of the zygoma It lies in a bony fossa on the front of the apex of the petrous temporal and below this covers that part of the

[1] It thus passes through a short of foramen formed partly by the notch in the sharp upper border of the petrous temporal and partly by the attached margin of the tentorium which bridges over it (Fig 139)

[2] Notably ganglionitis, producing shingles or herpes

cartilage of foramen lacerum which overlies the internal carotid artery. It is enclosed in a sheath of dura mater, known as the cavum meckeli, to the roof of which it is firmly attached, while only loose areolar tissue[1] connects it to the floor.

To its *outer side* the ganglion has the foramen spinosum transmitting the middle meningeal artery, which is therefore, *an obstruction in approaching it by the temporal route*. To its *inner side* is the cavernous sinus, the internal carotid artery, and the 3rd, 4th, and 6th nerves (Figs. 131 and 132).

To the inner side of these again is the pituitary body.

Above the ganglion is the uncus and temporo-sphenoidal lobe, *deep* to it are the greater and lesser superficial petrosal nerves, the *motor root of the 5th* and, as has been said before, the internal carotid artery.

The Motor Portion of the 5th nerve has no connection with the ganglion, but lies on its deep surface, crossing from the medial to the lateral side to join the third division of the trigeminal, and eventually supplies the six muscles of mastication.

The *posterior border of the ganglion* is concave, and receives the expanded sensory root. From its anterior convex border the three divisions of the 5th nerve are given off, namely:

The first or ophthalmic,

The second or maxillary, and

The third or mandibular.

Apart from these branches the ganglion receives communications from the sympathetic round the internal carotid artery and from its posterior part a few filaments pass to the dura.

Small *accessory ganglia* may be found along the concave border of the Gasserian ganglion corresponding to the accessory ganglia found on the posterior root between the posterior root ganglion and the spinal cord.

The Ophthalmic Nerve

The Ophthalmic Nerve, the smallest of the three divisions of the trigeminal, comes off the medial and upper part of the convex anterior border of the Gasserian ganglion.

It runs forwards in the lateral wall of the cavernous sinus enclosed in a separate sheath of dura which is a continuation forwards of Meckel's cave.[2] The 3rd and 4th nerves are above it, the internal carotid artery and 6th nerve medial, and the maxillary nerve below and lateral.

After a course of about 1 in. (2.5 cm.) it divides just behind the superior orbital (sphenoidal) fissure into three branches, *lacrimal, frontal,* and *naso-ciliary*, which pass through the fissure to enter the orbit.

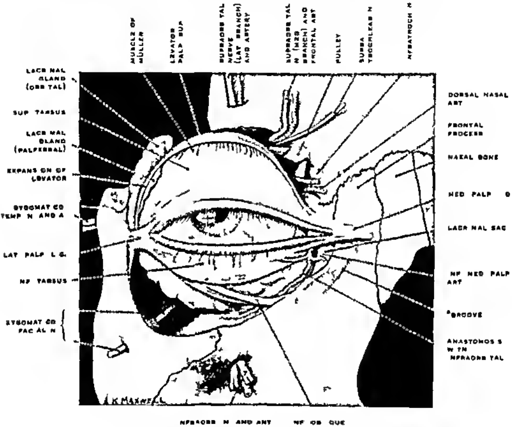
Communications.—*In the cavernous sinus* it is joined by branches of communication

[1] According to Burr and Robinson (*Anat. Rec.*, 1925, xxix, 269) there is an extensive subarachnoid space around the roots of the nerve and proximal two thirds of the ganglion which communicates freely with the cisterna pontis and accounts for some of the disastrous results from injections of the Gasserian ganglion.

[2] Hence it is necessary to incise the dura of the outer wall of the sinus and *then* the proper sheath of the nerve before it is exposed (Hovelacque).

from the 3rd, 4th and 6th nerves (probably proprioceptive) and from the sympathetic round the internal carotid artery. It also sends a *recurrent* branch (the nervus tentorii of Arnold) to the tentorium. This nerve comes off near the origin of the ophthalmic and passes backwards to cross the 4th. It is usually closely adherent to this nerve and not infrequently passes through it (hence it has been described as a branch of the trochlear) to reach the tentorium.

The Lacrimal Nerve, the smallest of the three terminal branches of the ophthalmic, arises in the anterior part of the middle cranial fossa.



The groove on the frontal process of the superior maxilla (not the nasal bone) is marked to draw attention to its presence as it is liable to be mistaken for the lacrimal fossa in exposing the lacrimal sac.

FIG. 14[illegible].—DISSECTION OF ORBIT FROM IN FRONT.

Stage 3. Septum removed.

(*Author's dissection.*)

It passes through the *wide* portion of the superior orbital (sphenoidal) fissure above the annulus of Zinn to the outer side of the frontal and 4th nerves and above and medial to the ophthalmic vein. In the orbit the nerve runs outwards parallel to and close in front of the narrow[1] portion of the sphenoidal fissure,

[1] As pointed out by Hovelacque, it does not pass through this narrow portion of the fissure as is usually stated and figured.

then forwards [1] along or just lateral to the upper border of the external rectus muscle to reach the lacrimal gland In the last portion of its course i e for the

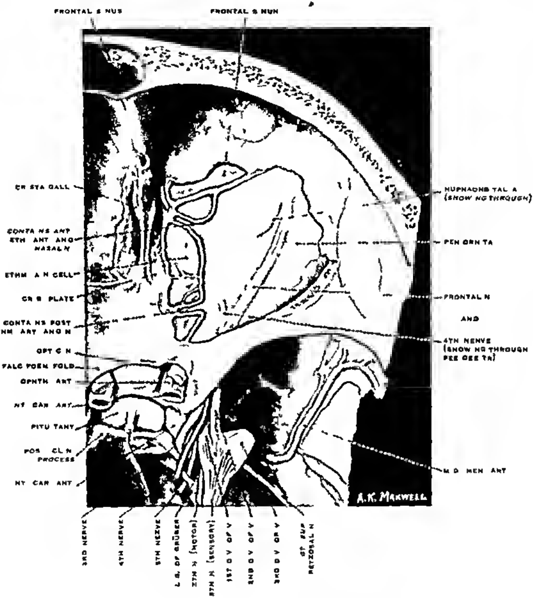


FIG 143.—DISSECTION OF ORBIT FROM ABOVE
Stage 1 To show the periorbita the roof has been removed
(*Author's dissection*)

distal two thirds of its relation with the external rectus, it is accompanied by the lacrimal artery

[1] The course of the lacrimal nerve is well described by the expression en baïonnette that is following the shape of the old fashioned bayonet ┌┘ (Hovelacque and Reinhold)

Just before reaching the gland the nerve sends an anastomotic twig to the zygomatic (temporo malar) nerve, then, having passed through the gland to which it sends branches, it supplies the conjunctiva and the skin of the outer part of the upper and lower lids which it reaches by piercing the palpebral fascia

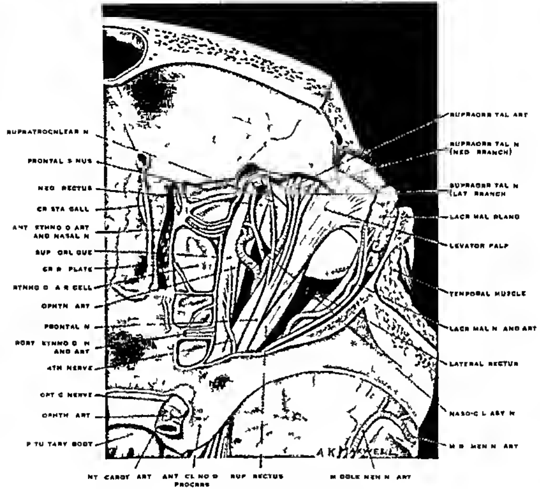


FIG 144 —DISSECTION OF ORBIT FROM ABOVE
Stage 2 Periorbita removed
(*Author's dissection*)

Variations —Absence of the lacrimal nerve has been recorded Sometimes the nerve is much smaller than usual and then is reinforced by a bigger anastomotic branch from the temporal branch of the temporo-malar (Turner Hyrtl quoted by Quain) On the other hand, the lacrimal may replace this temporal branch (Thane)

A fairly constant branch to the lacrimal appears to come from the 4th nerve, but most probably this is really derived from the ophthalmic Communications from the naso-ciliary and superior maxillary nerves have been seen by Delbet

The Frontal Nerve, the largest of the three branches of the ophthalmic, arises in the cavernous sinus just behind the sphenoidal fissure through which it enters the orbit

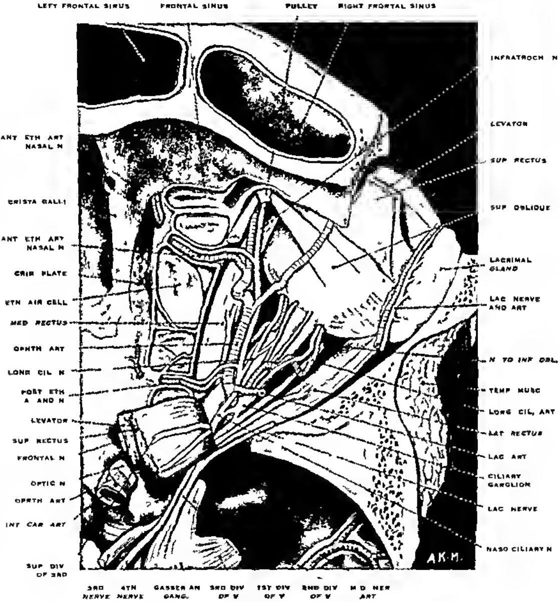


Fig 145 —Dissection of Orbit from Above
Stage 3 Levator and superior rectus reflected
(*Author's dissection.*)

In the fissure it is placed above the annulus of Zinn between the lacrimal and the trochlear

It runs almost directly forwards under the periosteum (periorbita) and on the levator palpebræ superioris.

About the middle of the orbit it divides[1] into *supratrochlear* and *supraorbital branches*.

The Supratrochlear Nerve (Fig. 144), much smaller than the supraorbital, runs inwards and forwards to pass above the pulley of the superior oblique near which it sends a twig of communication to the *infratrochlear* branch of the nasal.

In company with the *frontal* artery and under cover of the orbicularis and the corrugator supercilii the supratrochlear curls up over the orbital margin about 1/2 in. (1.25 cm.) from the mid line. It sends branches of supply to the skin, the lower part of the forehead on one or other side of the mid line and to the upper lid and the conjunctiva.

The Supraorbital Nerve, much the larger of the terminal branches of the frontal, continues the direction of the parent nerve. It lies on the levator with the supraorbital artery medial, and leaves the orbit in company with this vessel by the supraorbital notch or foramen.

Very often the nerve divides within the orbit into medial and lateral branches (Fig. 144). The lateral branch then occupies the supraorbital notch, and the medial passes out of the orbit about midway between the pulley of the superior oblique and the supraorbital notch. Usually it has a notch (frontal notch of Henle) or rarely a foramen of its own.

The supraorbital nerve breaks up into branches which anastomose with each other and supply the forehead and scalp to the vertex or even farther back, the upper eyelid, and the conjunctiva. Those to the *scalp* run up on the bone (sometimes grooving it) under the orbicularis and frontalis, which they pierce at intervals. Those to the upper lid pass through the orbicularis. The nerve also sends a twig to the diploe and frontal sinus via a small aperture in the floor of the supraorbital notch.

The Naso-ciliary (Nasal) Nerve arises from the inner and lower part of the ophthalmic, being as a rule the first of the three terminal branches to be given off. Intermediate in size between the lacrimal and frontal, it lies at first in the lateral wall of the *cavernous sinus*. It passes through the *superior orbital (sphenoidal) fissure* within the annulus of Zinn, between the two divisions of the 3rd nerve, close to the *sympathetic root* of the ciliary ganglion, which is below and medial.

In the *orbit* it runs inwards, with the ophthalmic artery, above the optic nerve, in front of the superior division of the 3rd nerve (Fig. 145) and below the superior rectus muscle.

It now passes between the superior oblique and internal rectus to leave the orbit with the anterior ethmoidal artery by the anterior ethmoidal canal, which is placed between the frontal and ethmoid bones. It appears in the *anterior cranial fossa* at the side of the cribriform plate of the ethmoid, the lateral part of which it grooves to reach a special slit between the forepart of this plate and the frontal bone,

[1] *Variations.*—The point of division of the frontal varies greatly. It may be anywhere from the origin of the nerve to just behind the orbital margin.

which leads it to the *roof of the nose* In this portion of its course it lies partly under or entirely in front of the anterior portion of the olfactory lobe (Fig 153)

In the *nasal cavity* it gives branches to the anterior part of the septum, and to the outer wall of the nose including the anterior portions of the middle and inferior turbinals The nasal nerve next lies in a groove (Figs 12 and 153), sometimes converted into a canal on the posterior aspect of the nasal bone between

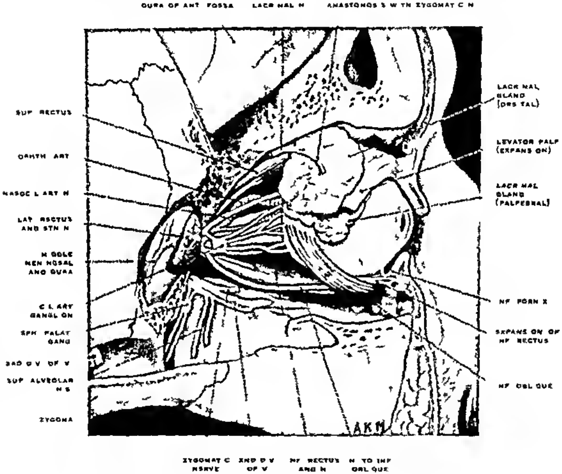


FIG 14C —DISSECTION OF THE ORBIT FROM THE OUTER SIDE
(*Author's preparation*)

which and the lateral nasal cartilage it makes its appearance on the *face* to supply the skin of the lower and anterior part of the nose

Thus we find the nerve successively in the middle cranial fossa, in the superior orbital (sphenoidal) fissure, in the orbit, in the anterior ethmoidal canal, in the anterior cranial fossa in the nose and lastly on the face

Branches —(*a*) *The Long or Sensory Root of the Ciliary Ganglion* is given off in or just in front of the superior orbital (sphenoidal) fissure It is a slender nerve about $\frac{1}{4}$ in to $\frac{1}{2}$ in (6–1 25 cm) long which passes along the outer side

of the optic nerve to reach the upper and posterior part of the ganglion

(*b*) *The Long Ciliary Nerves* two in number come off as the nasal crosses the optic nerve, to the inner side of which they come to lie They run with the short ciliaries anastomosing with them pierce the sclerotic, and passing between this and the choroid supply *sensory* fibres to the *iris cornea,* and *ciliary muscle* and *dilatator* fibres to the *pupil* (see p 275)

(*c*) *The Posterior Ethmoidal Nerve* (of Luschka) is only present sometimes

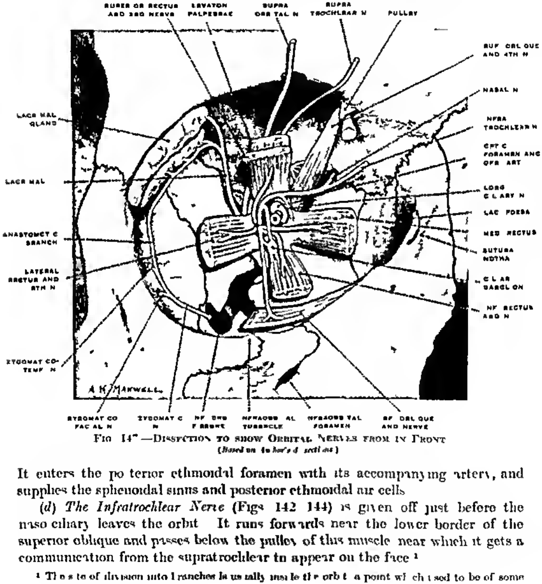


FIG 14?—DISSECTION TO SHOW ORBITAL NERVES FROM IN FRONT
(Based on Schafer's dissections)

It enters the posterior ethmoidal foramen with its accompanying artery, and supplies the sphenoidal sinus and posterior ethmoidal air cells

(*d*) *The Infratrochlear Nerve* (Figs 142 144) is given off just before the naso ciliary leaves the orbit It runs forwards near the lower border of the superior oblique and passes below the pulley of this muscle near which it gets a communication from the supratrochlear to appear on the face [1]

[1] The site of division into branches is usually inside the orbit a point which used to be of some practical importance (Bardal 1887)

It breaks up into its branches which supply the skin and conjunctiva round the inner angle of the eye the root of the nose the lacrimal sac and canaliculi, and the caruncle It anastomoses with the supraorbital and infraorbital nerves

Varieties —Absence of the infratrochlear nerve has been noted (Testut) its place being taken by the supratrochlear Branches have been seen passing from the nasal to the levator (Fäsebeck), to the 3rd and 6th nerves (Switzer), *to the mucous membrane of the frontal*

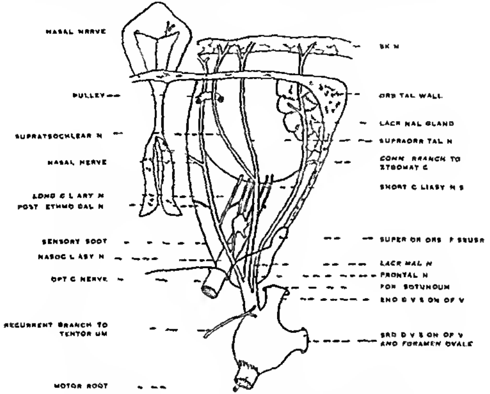


Fig 148 —Diagram of the First Division of the 5th Nerve (L W)

sinus and ethmoidal air-cells as the nerve lies in the anterior ethmoidal canal (Meckel and Langenbeck)

The Nasal Nerve, *either directly through the long ciliaries or indirectly through the short ciliaries is the sensory nerve to the whole eyeball*

Thus there is good anatomical ground for the statement that if the nasal branch of the ophthalmic (division of the trigeminal) is involved in Herpes ophthalmicus the eye is usually affected as well

The Ciliary Ganglion [1]

The Ciliary (*Ophthalmic or Lenticular*) *Ganglion* is a small reddish grey some what quadrilateral body about the size of a pin's head (2 mm in antero posterior

[1] The ciliary ganglion is most easily found by first isolating the nerve to the inferior oblique This can be done by exposing the inferior oblique from in front then it is quite easy to see the nerve as it crosses the middle of the posterior border By pulling gently on the nerve it can readily be identified behind the globe and so leads one to the ciliary ganglion

and 1 mm in vertical diameter), situated at the posterior part of the orbit about 1 cm from the optic foramen between the optic nerve and the external rectus muscle It is in close contact with the nerve, but separated from the muscle by some loose fat Usually also it is in close relation with the ophthalmic artery (Figs 145, 146)

It receives posteriorly three roots (Fig 149)

(1) The long or sensory root,

(2) The short or motor root,

(3) The sympathetic root

(1) *The Long or Sensory Root* comes from the naso ciliary, and is given off

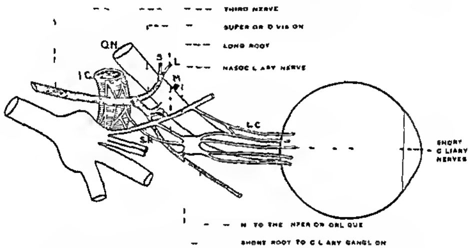


FIG 149—SCHEME OF THE 3RD NERVE AND CILIARY GANGLION (L W)

O N = optic nerve I C = internal carotid artery S nerve to superior rectus L = nerve to levator M = nerve to medial rectus L C — long ciliary nerve S R = sympathetic root (*After Cunen*)

just after that nerve has entered the orbit It is a slender nerve about 6 to 12 mm long, which passes along the outer side of the optic nerve to reach the upper and posterior part of the ganglion It contains sensory fibres from the *cornea iris* and *ciliary body* and possibly (from the sympathetic fibres which often join it) dilator fibres to the pupil

(2) *The Short or Motor Root* comes from the nerve to the inferior oblique a few millimetres beyond the point where the nerve arises from the inferior division of the oculo motor much thicker than the sensory root only about 1 to 2 mm long and passes upwards and forwards to enter the postero inferior angle of the ganglion It carries the fibres of supply to the sphincter pupillæ and the ciliary muscle

(3) *The Sympathetic Root* comes from the plexus around the internal carotid artery It passes through the sphenoidal fissure within the annulus of Zinn, infero medial to the naso ciliary It lies below and close to the long root, with

which it may be blended and enters the posterior border of the ganglion between the other roots It carries constrictor fibres to the blood vessels of the eye, and possibly dilator fibres to the pupil

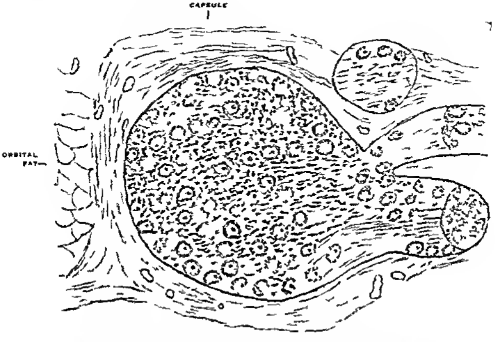


Fig 150 —Section of the Ciliary Ganglion (Mallory's Phosphotungstic Hæm)
Note that the ganglion cells are also found in the branches of the ganglion
(Author's preparation)

Branches of the Ganglion

The Short Ciliary Nerves six to ten in number, are delicate filaments which come off in two groups from the antero superior and antero inferior angles of the ganglion respectively They run a wavy course, with the short ciliary arteries, above and below the optic nerve the lower group being the larger As they pass forwards they anastomose with each other and with the long ciliaries and having given branches to the optic nerve and ophthalmic artery pierce the sclera around the optic nerve They run anteriorly between the choroid and sclera, grooving the latter to reach the ciliary muscle on the surface of which they form a plexus which supplies the iris, ciliary body, and cornea

The ciliary ganglion which contains multipolar[1] nerve cells forms a cell station for the fibres of the 3rd nerve Yet the short ciliary nerves are medullated Thus, as Gaskell pointed out they are the only medullated post ganglionic fibres in the body (see also p 360)

Varieties —The short root may be absent, the ganglion then sitting on the nerve to the inferior oblique Additional roots have been described from the trochlear (Krause and

[1] Ganglion cells are also often found along the short ciliary nerves (Figs 150 and 151)

Tilgman), from the 6th nerve in a case where the oculo motor was absent (Pourfour du Petit), and from the lacrimal (Quain). There may be multiple sympathetic roots. The *sensory root* may come from the ophthalmic or the supraorbital (Switzer).

FIG. 151.—SHOWING GANGLION CELLS IN THE SHORT CILIARY NERVES (*Author's preparation.*)

THE SUPERIOR MAXILLARY NERVE

The Superior Maxillary Nerve, or second division of the 5th nerve, is intermediate in size between the ophthalmic and the mandibular, and comes off the middle of the convex anterior border of the Gasserian ganglion. It runs forwards in the lower angle of the cavernous sinus in a groove (Figs. 131 and 182) on the great wing of the sphenoid, which leads it to the foramen rotundum.

It passes through this foramen (which is usually a canal) into the pterygo-palatine (spheno maxillary) fossa. It now turns laterally behind the orbital process of the palate bone, then, changing its name to infraorbital, runs forwards first in the infraorbital groove, then in the infraorbital canal to emerge on the face by the infraorbital foramen and divide into its terminal branches—palpebral, nasal, and labial.

Relations.—(*a*) *In the Cranial Cavity*.—It lies in the lower angle of the cavernous sinus, surrounded by a cuff of dura mater continuous with that of Meckel's cave. *Above* it, is the ophthalmic division of the 5th nerve, while *laterally* is the temporal lobe of the brain.

When the sphenoidal sinus is large it may send a prolongation into the great wing of the sphenoid between the foramen ovale and rotundum *which may account for the nerve being involved in sinus disease* (Hovelacque)

(*b*) *In the Pterygo palatine* (*Spheno maxillary*) *Fossa* —Here the nerve is in close relation with the termination of the internal maxillary artery and a plexus of veins It is also closely related to the ethmoidal air cells in the orbital process of the palate bone *and may be involved in ethmoidal disease here* (Ramadier)

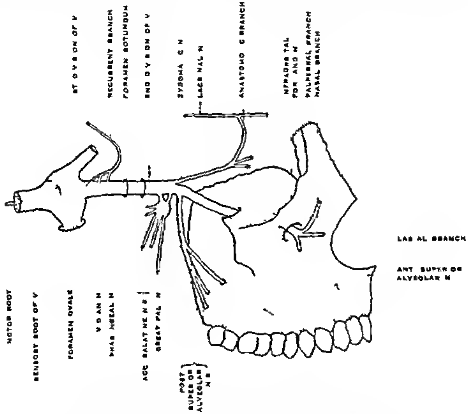


FIG 15? —DIAGRAM OF THE SECOND DIVISION OF THE 5TH NERVE (L.W.)

(*c*) *In the Floor of the Orbit* —In the infraorbital groove it is covered by periorbita and in the canal by a thin plate of bone as well

It causes a ridge in the roof of the maxillary antrum and sometimes when the canal is deficient may actually be in contact with the mucous membrane

The infraorbital artery is a terminal branch of the internal maxillary at first lateral in the canal it passes through the nerve to lie on its medial side

(*d*) *On the Face* —The sharp upper margin of the infraorbital foramen, which is the point of exit of the infraorbital nerve can often be felt about ½ in below the tubercle on the lower orbital margin which marks the suture between the zygomatic bone and the maxilla The nerve lies here deep to the elevator of the upper lip and the orbicularis oculi

	BRANCHES
In the cranial cavity	Recurrent or Meningeal
In the spheno maxillary fossa	Zygomatic (temporo malar) Spheno palatine Posterior superior alveolar (dental)
In the infraorbital canal	Middle superior alveolar (dental) Anterior superior alveolar (dental)
On the face	Palpebral Nasal Labial

The *recurrent* or *meningeal branch* comes off close to the Gasserian ganglion, and follows the middle meningeal artery

The *Zygomatic (Temporo malar or Orbital) Nerve* enters the orbit by the spheno maxillary (inferior orbital) fissure and soon divides into zygomatico temporal (*temporal*) and zygomatico facial (malar) branches

The Zygomatico temporal Branch runs upwards in a groove on the *outer wall* of the orbit, *gives a communicating twig to the lacrimal nerve*, which carries secretory fibres to the lacrimal gland and then enters a canal in the malar bone which leads it to the temporal fossa It now ascends pierces the temporal fascia behind the malar tubercle, and having joined with branches of the facial supplies the skin over the anterior part of the temporal region up to the lateral orbital margin

The Zygomatico facial (Malar) Branch likewise enters a canal in the malar bone which leads it to the face where, having joined with branches of the facial and pierced the orbicularis it supplies the skin over the malar bone

Varieties —The whole zygomatic nerve may enter one canal and then divide in the bone it If The lacrimal communication may replace the zygomatico temporal branch and a twig from the infraorbital take the place of the zygomatico facial branch

The Zygomatico facial Branch may come out on the face as two branches

The Spheno palatine Branches two in number descend to the spheno palatine ganglion

The Posterior Superior Alveolar (Dental) Branches arise just before the nerve enters the infraorbital groove They run down the posterior surface of the maxilla supply the gum enter this aspect of the bone by the posterior dental canals to reach the *upper molar teeth*, to each of which they send three branches, which enter the apices of the fangs

The Middle Superior Alveolar (Dental) Nerve comes off in the back part of the infraorbital canal runs down in the lateral wall of the antrum to supply the *two bicuspid teeth* It also sends twigs to the gums and mucous membrane of the antrum

The Anterior Superior Alveolar (Dental) Nerve arises from the lateral side of

the infraorbital near the infraorbital foramen below which it passes to reach its medial side, then runs down in the anterior wall of the antrum to the mucous membrane of which it gives twigs and supplies the *upper incisors* and the *canine*, and also sends a branch to the inferior meatus of the nose

The Inferior Palpebral Branch runs upwards and supplies the skin and conjunctiva of the lower lid

The Lateral Nasal Branches supply the skin on the side of the nose

The Superior Labial Branches supply the anterior part of the cheek, and the skin and mucous membrane of the upper lip

The Spheno palatine Ganglion

The spheno palatine or Meckel s ganglion is situated in the upper part of the spheno maxillary (pterygo palatine) fossa, just lateral to the spheno palatine foramen and suspended from the maxillary nerve by its spheno palatine branches (Figs 146 and 152)

Roots [1]

Sensory —Spheno palatine nerves

Sympathetic and Motor.—From the vidian This nerve is formed in the cartilage of the foramen lacerum by the union of the great superficial petrosal, from the geniculate ganglion of the facial, with the great deep petrosal of the sympathetic plexus around the internal carotid artery (Fig 153) It passes through the vidian canal in the sphenoid bone, which commences just above the pterygoid tubercle and ends in the spheno maxillary fossa, where it joins the ganglion

It is believed that the great superficial petrosal carries fibres which will eventually supply the lacrimal gland, which they reach via the orbital branches of the spheno palatine ganglion or the zygomatic nerve and its anastomosis with the lacrimal

Branches of the Ganglion

Ascending	Orbital
Descending	Great (anterior) palatine Accessory palatine
Medial	Nasal
Posterior	Pharyngeal

The Orbital Branch passes into the orbit via the inferior orbital (spheno maxillary) fissure to supply the periosteum the *posterior ethmoidal air cells*, and sphenoidal sinus (Luschka)

Branches [2] have also been described going to the 6th nerve (Bock and

[1] Probably the only nerve which actually makes a cell station in the ganglion is the great superficial petrosal The others simply pass by or through it

[2] Quoted by Quain

Valentin) to the ciliary ganglion (Tiedemann), and to the optic nerve (Herzel and Arnold)

The Great Palatine Nerve runs down with the accompanying arteries and veins in the palatine canal, and appears on the hard palate through the great palatine foramen It supplies the mucous membrane of the *gums* and *hard palate* and the *inferior meatus* of the nose

The Accessory Palatine Nerves run down behind the great palatine They come out

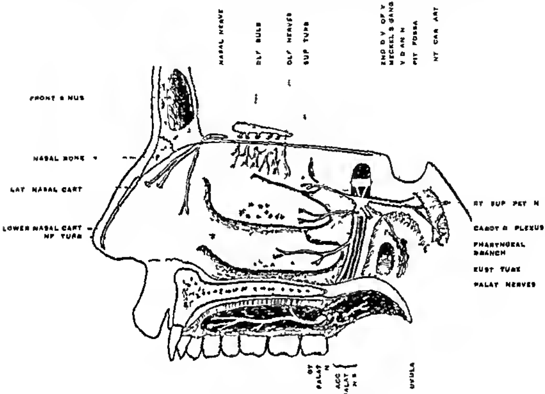


FIG 153 —NERVES OF THE LATERAL WALL OF THE NOSE
(From the Author's Shorter Anatomy)

through the accessory palatine foramina and supply the soft palate uvula and palatine tonsil

The Nasal Branches enter the nose by the spheno palatine foramen and supply the *superior* and *middle turbinates* the upper part of the *septum* and the posterior ethmoidal air cells

The Naso-palatine Nerve enters the nose by the spheno palatine foramen crosses the roof then descends in a groove in the septum, giving branches to the mucous membrane all along its course It passes through the foramen of Scarpa (the left nerve anterior the right posterior) and ends in the mucous membrane of the hard palate and gums

The Pharyngeal Branch passes backwards to supply the pharynx behind the Eustachian tube

THE MANDIBULAR NERVE

The mandibular or third division of the 5th nerve is made up of two roots

The Sensory Portion comes from the Gasserian ganglion, the motor part is the

motor root of the trigeminal, the whole of which goes with this division to supply the six muscles of mastication

The two roots pass through the *foramen ovale* and almost immediately unite into one trunk, which has the tensor palati and Eustachian tube medial and the external pterygoid and middle meningeal artery lateral

The Foramen Ovale lies in the outer side of the base of the external pterygoid plate *With the mouth open so as to get the coronoid process out of the way pass a needle just below the zygoma and* 1 *in* (2 5 *cm*) *in front of the temporo mandibular joint directly inwards It strikes the external pterygoid plate Now direct it a little backwards and upwards and it enters the foramen* 1¾ *in* (4 5 *cm*) *from the surface If pushed too far it enters the Eustachian tube*

Nucleus and Central Connections of the 5th Nerve

The Sensory Nucleus of the 5th nerve is shaped like a tadpole (Fig 154) The head forming the main sensory nucleus (nucleus sensibilis *a* of Winkler) lies

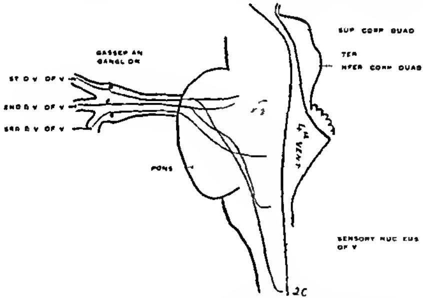


Fig 154 —Scheme of the Sensory Nucleus of V

Note that the fibres of the 1st division go to the lowest part of the nucleus at the level of the 2nd *cervical nerve i e the face is represented upside down in the long spinal nucleus of the trigeminal*

in the lateral dorsal part of the pons beneath the superior cerebellar peduncle The tail forms the bulbo spinal nucleus (nucleus sensibilis b + nucl gelatinosus of Winkler) and becomes continuous with the substantia gelatinosa of Rolando at the level of the 2nd cervical vertebra

The fibres of the sensory root which come from the Gasserian ganglion on *entering the pons* divide into ascending and descending branches as does any ordinary spinal nerve The ascending fibres mostly end in the upper expanded part or main sensory nucleus

The descending fibres form the *tractus spinalis* of the trigeminal nerve, and enter the bulbo spinal nucleus at various levels

The main sensory nucleus (nucleus sensibilis *a* of Winkler) most probably has to do with proprioceptive impulses The tail receives heat, cold, pain, and touch fibres, those from the ophthalmic division go to the *lowest* part, those from the maxillary division are next while those from the mandibular division are uppermost This arrangement, as pointed out by Paton, explains *how in syringomyelia involving the upper part of the cord, the forehead and eye may be affected and the buccal area escape* Also the fact that the great occipital nerve comes from the 2nd cervical segment, where the ophthalmic portion of the nucleus ends, *may explain the frequency of occipital headaches in eye disease*

The fibres from the sensory nucleus pass for the most part via the medial fillet to the thalamus of the opposite side while the heat cold and pain fibres pass up in the spino thalamic tract

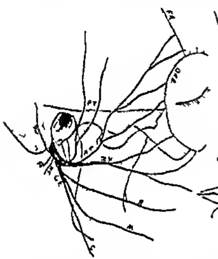


FIG 155—DIAGRAM OF THE FACIAL NERVE

FR = edge of the frontalis ORB = edge of orbicularis PT = posterior temporal AT anterior temporal PA = posterior auricular D = digastric SH = stylo hyoid CF = cervico facial ZY = zygomatic B = buccal M = mandibular C = cervical

The Motor Nucleus lies in the lateral tegmental portion of the pons medial to and nearer the floor of the 4th ventricle than the head of the sensory nucleus It is a continuation of the *nucleus ambiguus* in line with the nucleus of the facial

The Mesencephalic Root starts in unipolar cells lateral to the iter, and passes down the mid brain close to the 4th nerve

It probably carries proprioceptive impulses from the masticatory and eye muscles

Connections—The 5th nerve has taken on the sensory function of almost all the nerves of the head Its connections are therefore very extensive

Function—The 5th nerve carries protopathic and epicritic sensation from the areas which it supplies, probably also proprioceptive impulses from the eye muscles and trophic fibres **Division** of the 1st division of the 5th nerve tends to produce neuroparalytic keratitis, the mechanism of its production is not entirely explained the trophic fibres no doubt, at any rate, play some part in this

THE 7TH CRANIAL OR FACIAL NERVE

The facial nerve emerges from the brain at the lower border of the pons in the recess between the olive and the restiform body (Fig 174) It is here some distance lateral to the

6th, but medial to the pars intermedia and the auditory. From its superficial origin it runs outwards and forwards in the posterior cranial fossa to the internal auditory meatus. In this part of the course it lies in a groove on the upper surface of the 8th, with the pars intermedia between them (Fig. 175). Accompanied by the internal auditory artery these structures enter the meatus, at the bottom of which is the lamina cribrosa, divided into four parts by a horizontal and a less marked vertical partition. The 7th nerve, now fused with the pars intermedia, passes through the antero-superior quadrant, and enters the aqueduct of Fallopius. It, now, for a short distance (4 mm.) continues laterally more or less in the direction of the internal auditory meatus, then bends backwards over the vestibule to reach the middle ear. The geniculate ganglion is placed on this bend of the facial nerve. In the middle ear it lies in a bony[1] canal, placed between the roof and medial wall, and running above the promontory and fenestra ovalis. At the junction of the medial and posterior walls the 7th nerve makes a second bend, downwards this time, and escapes from the skull through the stylo-mastoid foramen.

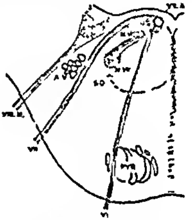


FIG. 156.—PLAN OF THE ORIGINS OF THE 6TH AND 7TH CRANIAL NERVES.

The outline represents a transverse section of the lower part of the pons, on to which the course of the facial nerve is projected. VI = 6th nerve. N VI = its nucleus. VII = facial nerve. VII A = the ascending portion of its root supposed to be seen in optical section. N VII = its nucleus. S O = superior olive. A V = ascending or bulbar root of fifth nerve. VIII M = mesial root of auditory nerve.

(After Schwalbe, from Quain's "Anatomy.")

The descending portion of this second bend forms a ridge on the medial wall of the aditus, and has above it the bulge formed by the lateral semicircular canal. Having escaped from the skull the facial runs forwards in the parotid, lying here superficial to the temporo-maxillary vein and the external carotid artery, and divides in the substance of the gland into its terminal branches. It is of practical importance to note that in the infant, who has no mastoid process, *the 7th nerve at its exit from the skull lies more on the outer than the under aspect of the skull, and if the usual incision behind the ear be made to expose the mastoid antrum it will almost certainly be injured.*

BRANCHES

In the *temporal bone*
- (a) Great superficial petrosal
- (b) Nerve to the stapedius
- (c) Chorda tympani.

At its exit from the stylo-mastoid foramen
- Posterior auricular
- Digastric
- Stylo-hyoid

On the face
- Temporal
- Zygomatic
- Buccal
- Mandibular
- Cervical

The Great Superficial Petrosal comes off the geniculate ganglion. It passes through the hiatus Fallopii, then runs in a groove on the anterior surface of the petrous temporal

[1] *This may be wanting in parts, and hence the nerve may more easily be affected in inflammation of the tympanum.* The fibres affected earliest are those supplying the orbicularis (according to Askerson the winking reflex goes first), which suggests that in the cross-sectional anatomy of the nerve these fibres are most superficial.

(Fig 130) under the Gasserian ganglion to the foramen lacerum Here it unites with the great deep petrosal from the sympathetic plexus on the internal carotid artery to form the vidian nerve, which joins Meckel's ganglion via the Vidian (pterygoid) canal (Fig 153)

The great superficial petrosal contains sensory fibres to the mucous membrane of the soft palate, and also secretory fibres to the mucous and lacrimal glands (see also p 155) It has been described as the nerve of tear secretion

The Temporal Branches run upwards over the zygoma The posterior of these *supply the attollens auriculam the anterior branch (or branches) crosses the* zygoma ½ in to ¾ in behind the external angular process of the frontal and supplies the frontalis and corrugator supercilii and upper part of the orbicularis According to Trotter this is the only motor nerve of any practical importance in the scalp It may be cut in the incision for removal of the Gasserian ganglion with a resulting smoothness of the forehead and drooping of the eyebrow

The Zygomatic or Malar Branches cross the malar bone to supply the lower part of the orbicularis

Nucleus and Connections —The facial nerve is usually regarded as consisting of a motor portion the facial proper and a sensory portion the pars intermedia But the pars intermedia contains secretory fibres as well

The sensory portion of the pars intermedia rises in the geniculate ganglion which consists of unipolar cells whose axones divide in a T shaped manner The central processes form part of the nervus intermedius the peripheral processes the sensory fibres of the chorda tympani and great superficial petrosal

The central fibres pass through or dorsal to the spinal root of V to reach the upper part of the glosso pharyngeal nucleus

The motor (somatic) nucleus of the 7th consists of large cells homologous with the nucleus ambiguus the upward continuation of the anterior horn of the spinal cord

The nucleus of the 7th is situated near its point of exit but the fibres do not pass straight out They run first backwards and medially through the pons to the floor of the 4th ventricle where they cross and run upwards medially to the 6th nerve nucleus forming the colliculus facialis in the floor of the ventricle The fibres now turn laterally cross the 6th nucleus again pass forwards between their own nucleus and the spinal root of the 5th nerve to emerge between the olive and the restiform body (Figs 156 174)

Communications —(*a*) From the 3rd probably to supply the orbicularis oculi the frontalis and the corrugator, for in supranuclear lesions of the 7th these are not involved

(*b*) From the 12th to the orbicularis oris (probably)

(*c*) From the cortex of the opposite side via the pyramidal tract The crossing takes place in the pons *hence unilateral lesions here produce palsy of the face on the same side and on the opposite side of the rest of the body Note that in the*

Rolandic gyrus the face area comes next the arm, but in the internal capsule the shoulder and face fibres are together

The 8th Cranial or Auditory Nerve

The 8th cranial nerve consists of two portions a cochlear division which carries auditory impulses and a vestibular part, which has to do with equilibrium and sense of position

It is attached to the brain just below the lower border of the pons lateral to the 7th The pars intermedia runs between these and often curiously enough nearer the 8th

The 8th nerve runs outwards and forwards to the internal auditory meatus its two portions forming a groove in which the 7th rests, the pars intermedia lying between them

Accompanied by the internal auditory branch of the basilar artery, these structures enter the meatus at the bottom of which the 8th nerve divides into branches which pass through the lamina cribrosa

The cochlear portion passes through the lower and anterior quadrant to reach the cochlea The branches of the vestibular division pass through the two posterior quadrants Through the supero posterior quadrant go the nerves to the utricle, superior and lateral semicircular canals Through the infero posterior quadrant pass the nerves to the sacculus and posterior semicircular canal

Nuclei and Central Connections—The ganglion of the cochlear division, or ganglion spirale lies in the modiolus of the cochlea Its peripheral fibres come from the organ of Corti

The ganglion of the vestibular division or ganglion of Scarpa is in the internal auditory meatus Its peripheral fibres come from the vestibular apparatus The two nerves are united in the internal auditory meatus, and so run back to enter the brain below the pons lateral to the 7th nerve

The cochlear portion now goes to two nuclei one dorsal and one ventral to the restiform body From the dorsal nucleus run the striæ acousticæ (medullaris) which cross the floor of the 4th ventricle (Fig 84) and divide it into pontine and medullary portions and then join the lateral fillet of the opposite side

The fibres from the ventral nucleus also join the lateral fillet which makes connection with the inferior corpora quadrigemina, medial geniculate bodies, and finally terminate in the anterior transverse gyrus of Heschl (temporal lobe)

The vestibular fibres end in (a) the principal dorsal nucleus of the vestibular nerve which lies in the so called area acousticæ of the 4th ventricle, (b) Deiter s and Bechterew s nuclei in the side wall of the 4th ventricle, and (c) the cerebellum

Both the cochlear and vestibular divisions of the 8th nerve make connection *with the medial longitudinal bundle, and thus with the oculo motor nuclei*

CHAPTER VII

THE VISUAL PATHWAY

THE visual pathway may be divided into six parts

(1) The optic nerve
(2) The optic chiasma
(3) The optic tract
(4) The external geniculate body
(5) The optic radiations
(6) The striate area

THE 2ND CRANIAL OR OPTIC NERVE[1]

The Optic Nerve, ensheathed in pia, runs as a flattened band from the antero lateral angle of the somewhat quadrilateral chiasma forwards and outwards to the optic foramen (Fig 130) About half way along this course it receives a covering of arachnoid (Fig 129)

Becoming more oval, and acquiring a dural covering, it traverses this foramen, or more correctly this canal, and enters the orbit As a rounded cord it now runs forwards and slightly outwards and downwards in a somewhat sinuous manner[2] (to allow for ocular movements), and is attached to the back of the eye ball, just *above*[3] and 3 mm internal to its posterior pole (Fig 125, E)

Its total length is 5 cm, the intracranial portion being about 1 cm, the intracanalicular 6 mm, the intraorbital 3 cm, and the intraocular 0 7 mm

Relations —(a) *In the Cranial Cavity* —The nerve lies at first on the diaphragma sellæ, which covers the pituitary body, then on the anterior portion of the cavernous sinus

Above it is the *anterior perforated substance*, the medial root of the olfactory tract, and the *anterior cerebral artery* which crosses it from without inwards (Figs 130 and 175)

The Internal Carotid Artery is at first below, then lateral

The Ophthalmic Artery[4] usually comes off the internal carotid under the

[1] Although we speak of the optic *nerve*, it is very important to realise that it is really no nerve at all but essentially a *fibre tract* joining two portions of the brain

[2] Usually two curves can be recognised a posterior with its convexity outwards, and an anterior with its convexity downwards

[3] The point of attachment is usually described as 1 mm below and 3 mm internal to the posterior pole This can hardly be so since the centre of the macula is *below* the centre of the disc (See also figure in Testut, 8th edition, 1930)

[4] Fawcett, *Journ of Anat and Phys*, xxx, N S, x, 1896, pp 49–53

middle of the optic nerve (Figs 145, 175), but since its course here is antero posterior, and that of the nerve outwards as well as forwards it may appear at the inner border of the nerve before it eventually passes laterally At any rate, in this first portion of its course it is nearer the inner border than the outer The nearer the origin of the artery is to the optic foramen, the nearer the *inner* side of the nerve is it placed, and vice versa

(*b*) *In the Optic Canal* the nerve is surrounded by its membranes, dura, arachnoid, and pia, but it should be carefully noted that *above* these are firmly united to each other, to the periosteum, and to the nerve This clearly forms a point of fixation of the nerve, which might otherwise easily be pushed backwards and forwards in and out of the cranium, and thus be liable to injury (Schwalbe) This fixation of the nerve also accounts for the fact that in the optic canal the cranial subarachnoid space only communicates with that round the optic nerve below (see later, p 239)

The ophthalmic artery is crossing below the nerve in the dural sheath to the lateral side It leaves the dura at or near the anterior end of the canal

Medially the optic nerve is in relation with the sphenoidal air sinus or a posterior ethmoidal air cell, from which it may be separated by a thin plate of bone only *This provides the anatomical explanation of the nerve being affected in sinus disease and resulting in a retro bulbar neuritis*

Not infrequently the sphenoidal sinus or a posterior ethmoidal air-cell may invade the roots of the lesser wing of the sphenoid, and even the wing itself The nerve is then surrounded by air-cells

(*c*) *In the Orbit* (Figs 145 146 147) —At the optic foramen the nerve is surrounded by the origin of the ocular muscles, that of the superior and internal recti being closely adherent to the sheath *It is this connection which gives rise to the pain (in extreme movements of the globe) so characteristic of retro bulbar neuritis*

Between it and the origin of the lateral rectus are the two divisions of the 3rd nerve the naso-ciliary, the sympathetic, the 6th nerve, and sometimes the ophthalmic vein or veins

Farther forwards the muscles are separated from the nerve by orbital fat

The naso-ciliary nerve, the ophthalmic artery, and the superior ophthalmic vein cross the nerve superiorly from without inwards

The Ciliary Ganglion lies to the outer side of the nerve between it and the external rectus (Figs 145, 146)

The Long and Short Ciliary Nerves and Arteries gradually surround the nerve as it passes to the back of the eyeball

The Arteria Centralis Retinæ which comes off the ophthalmic near the optic foramen, runs forwards in or outside the dural sheath of the nerve, then with its accompanying vein *crosses the subarachnoid space* to enter the nerve on its under and inner aspect about ½ in (12 mm) behind the eye

(*d*) *The Intraocular Portion*—As the nerve passes into the eye its fibres lose their myelin sheaths, and at the same time there is diminution in the amount of supporting tissue

This results in the optic nerve being 3 mm in diameter at the back of the globe and only 1 5 mm at the lamina cribrosa

The intraocular portion of the optic nerve passes through the sclera, the choroid, and finally appears inside the eye as the "papilla" optica where it becomes continuous with the nerve fibre layer of the retina (Figs 157 and 159)

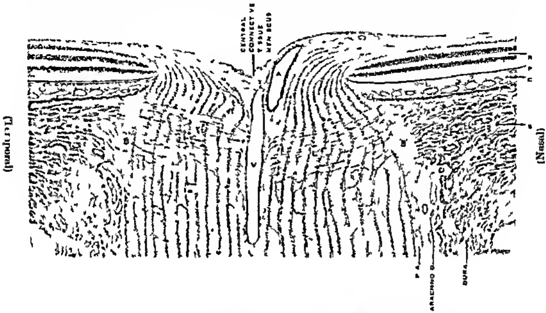


FIG 157—HORIZONTAL SECTION OF THE OPTIC NERVE HEAD
A = arteria centralis V = vena centralis B = border tissue L = lamina cribrosa R = retina I = pigment epithelium and hyaloid membrane C = choroid S = sclera

We may thus subdivide the ocular portion of the nerve into scleral, choroidal, and retinal parts

The junction between the medullated and non medullated parts of the nerve is at the back of the lamina cribrosa (Fig 158)—at the distal end of the subarachnoid space—but this is not a sharp line, for some fibres lose their myelin sheath proximal and some distal to this point

The layers of the *retina*, apart from the nerve fibres, end near the borders of the optic nerve, being separated from it, however, by a ring or partial ring of glial tissue called the *intermediary tissue of Kuhnt*[1] In the retinal portion the

[1] It is usually stated that the intermediary tissue of Kuhnt can be seen with the ophthalmoscope This can hardly be true since neuroglia is transparent and also the tissue is covered by the whole thickness of the nerve fibre layer of the retina as it curves round to pass into the optic nerve (Fig 159)

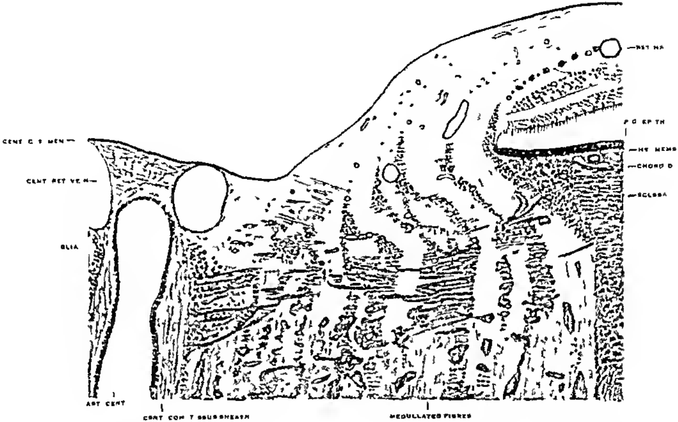


FIG 159 ANTERO POSTERIOR SECTION OF THE OPTIC NERVE HEAD (ZENKER MALLORY S TRIPLE STAIN)

Connective tissue blue

Non medullated nerve fibres light red medullated nerve fibres darker red Neuroglia still darker red Note that the anterior portion of the lamina cribrosa is glial the posterior consists of alternating layers of glia and connective tissue but mainly the latter

Glia separates the anterior portion of the sclera and the whole thickness of choroid from the nerve fibres and is continued anteriorly beyond the hyaloid membrane and pigment epithelium to form the intermediary tissue of Kuhnt Thus lies in the concavity of the nerve fibres as they sweep into the nerve

(Trans O S C A 1928)

nerve fibres are in separate bundles being separated from each other by columns consisting of neuroglial nuclei, fibres and vessels The individual fibres have extremely fine glial fibres around them

The termination of the retina is usually oblique, but more so on the nasal than on the temporal side, where it may be vertical The inner layers end before the outer

The pigment epithelium reaches up to the intermediary tissue The lamina vitrea may come right up to the nerve fibres

The Border Tissue [1] **(of Elschnig) (Fig 157)** of the optic nerve is a ring of white fibrous tissue which separates choroid and sclera from the nerve fibres With ordinary stains the border tissue differs but little from the sclera, although it can usually be distinguished from it In longitudinal sections it appears as a strip

FIG 158 —ANTERO POSTERIOR SECTION OF THE OPTIC NERVE TO SHOW MEDULLATED (CONGENITAL) NERVE FIBRES (WEIGERT'S STAIN)

Note that the normal medullation stops behind the lamina cribrosa in which region the fibres are non medullated

(From a s ek ly supplied by Mr Percy Flemming)

of tissue which separates the sclera from the optic nerve and is then continued forwards to delimit the choroid from the nerve fibres It consists of dense collagenous tissue, in which are also found many glial and elastic fibres and some pigment (Salzmann) It is better marked on the temporal than on the nasal side

Thus we see that none of the three tunics, except the membrane of Bruch, reaches right up to the nerve and even this is often held away by neuroglia (Fig 159)

The Scleral Canal is the canal through which the optic nerve passes to reach the retina It is bounded by the border tissue which separates the nerve fibres

[1] The border tissue is variously described Some hold that it belongs to sclera or choroid while others believe it is a continuation forwards of the pia

from the choroid and anterior third of the sclera proper It is some 0 5 mm long, and may run straight forward or be directed slightly nasally, temporally, or downwards

The Lamina Cribrosa consists of a series of sieve like membranes arranged transversely across the scleral canal, through the holes of which the fibres of the optic nerve pass (Figs 159 160, 161)

In order to understand its structure it is best to consider its development which in its *posterior portion* is like that of the septa of the optic nerve (see p 230) Thus in its scleral portion each trabecula of the lamina cribrosa is essentially the result of the ingrowth of a vessel derived from the circle of Zinn which is accompanied by connective tissue and glia

Each trabecula therefore has a vessel in its centre This is surrounded by connective tissue containing a large number of elastic elements This again is

FIG 160 —TRANSVERSE SECTION THROUGH THE ANTERIOR (GLIAL) PORTION OF THE LAMINA CRIBROSA (ZENKER MALLORY S TRIPLE STAIN)

Contrast with Fig 111 The glial fibres are stained red and the only blue staining connective tissue fibres are those round the vessels (shown here as dark rings and ovals)

(Author's preparation)

clothed by glia. Thus in its posterior portion in an antero posterior section of the optic nerve connective and glial tissues alternate (Fig 159) The anterior or choroidal portion of the lamina cribrosa is quite different in structure Here the trabeculæ consist of glial tissue only

The vessels from the circle of Zinn as they pass into the nerve divide and reunite to form a network which fills the interval between the side wall of the scleral canal and the connective tissue around the central vessels

The form of the lamina cribrosa on transverse section depends on this vascular network It also forms a net of narrow meshes which are transversely oval (Figs 160, 161)

In an antero posterior section it is seen that three to eight dense trabeculæ of hyaline appearance pass out of the side wall of the scleral canal The most posterior run inwards and backwards (Fig 159) to reach the central connective tissue a little in front of the outer limit of the sclera and make with the

FIG 161 —TRANSVERSE SECTION THROUGH THE POSTERIOR PORTION OF THE LAMINA CRIBROSA (ZENKER MALLORY'S TRIPLE STAIN)

The trabeculæ are much denser and consist mainly of connective (blue staining) tissue Note the contained vessel passing in from the sclera Contrast with Fig 160

(Author's preparation)

corresponding fibre of the opposite side a letter V with its concavity forwards The more anterior ones run more directly inwards but are all slightly concave anteriorly The limits of the lamina cribrosa are not quite definite, for posteriorly it shades off into the framework of the optic nerve and indeed some anatomists regard it as simply the continuation forwards of this framework

THE NEUROGLIA OF THE OPTIC NERVE HEAD

The optic nerve head is extremely rich in neuroglia This is due to the fact that the peduncle of the optic vesicle is first transformed into neuroglia and it is

only later that this neuroglial cord is traversed by nerve fibres (Redslob). Moreover at a certain stage of development the arteria centralis gives off the hyaloid artery. The origin of this artery is surrounded by a conical bud of neuroglia. Later the artery disappears and all that remains of the bud is a lamella of neuroglia which separates the central portion of the nerve head including the connective tissue round the central vessels (central connective tissue sheath) from the vitreous (Fig. 159).

This lamella of neuroglia, called the *central connective tissue meniscus* of Kuhnt, replaces the internal limiting membrane which is absent here but is continuous with it at the periphery (Fig. 159).

Since there are no connective tissue fibres (except those in walls of the vessels) in the choroidal and retinal portion of the scleral canal the supporting tissues are all neuroglial. Thus the great majority of cells seen in this region and forming the nuclear columns between the nerve fibre bundles are glial. According to Marchesani they are astrocytes.

The glial fibres also form the net which constitutes the choroidal portion of the lamina cribrosa.

Also radial neuroglial fibres become attached to the capillary walls by a sort of end plate (perivascularis gliæ).

Oligodendroglia is present (Lopez Enriquez) and is also interfascicular. The cells of Hortega (microglia) are also found and occur here with irregular or rod shaped bodies.

Not infrequently in infants a filamentary remnant of the hyaloid artery may be seen to enter the vitreous for 1–1½ mm. after a short intrapapillary course.

Rochon Duvigneaud describes the papilla as the umbilicus of the eye for it is traversed in the embryo by an artery which later disappears.

There are no fibres of Muller in the papilla and thus no material which binds the nerve fibres together at right angles to their course as occurs in the retina generally. They can thus be separated much more easily from each other and the tissue distended with œdematous fluid. This is no doubt the reason why the disc swells so easily in papillœdema while the neighbouring retina remains relatively flat.

Neuroglia also lines the anterior portion of the scleral and the whole of the choroidal portion of the canal of entry of the optic nerve (Fig. 159).

This neuroglia is continued anteriorly beyond the pigment epithelium where it forms the intermediary tissue of Kuhnt. The neuroglia here forms a mass of nuclei and circularly running fibres placed in the concavity of the nerve fibres of the retina as they curve round at the edge of the disc to enter the optic nerve (Fig. 159).

As regards the lamina cribrosa, the choroidal portion is entirely glial. In the scleral portion glial and connective tissue fibres alternate. It is usually stated that the most posterior laminæ contain no glia but while there is less glia than anteriorly, this tissue is always present.

The Sheaths of the Optic Nerve

The optic nerve in the cranial cavity is at first only surrounded by pia but after a short course gets a covering of arachnoid as well

At the optic foramen the cranial dura splits into two layers The outer becomes continuous with the periosteum of the orbit (periorbita) the inner forms the dural covering of the optic nerve

Thus in the canal and in the orbit the nerve is surrounded by three sheaths namely dura, arachnoid, and pia

Between the dura and arachnoid is the *subdural space*[1] and between the arachnoid and pia is the *subarachnoid space* Both these spaces communicate with the corresponding intracranial spaces thus fluid injected into the sub arachnoid space in the cranial cavity easily passes into the subarachnoid space around the optic nerve

The Dura consists of bundles of tough fibrous tissue which are larger than those of the sclera and composed of collagenous fibrillæ in which are found numerous elastic fibres

The central dural fibres run for the most part circularly the peripheral ones (i e those nearest the supravaginal space) tend to run longitudinally (Fig 84)

Flat connective tissue cells are found in the surface of the bundles

The inner surface of the dura is lined by endothelium and is connected to the pia by trabeculæ along which small vessels may run

Around the dura is the supravaginal space of Schwalbe who described it as a lymph space lined by endothelium It has however the structure of loose connective tissue which is easily distensible with fluid

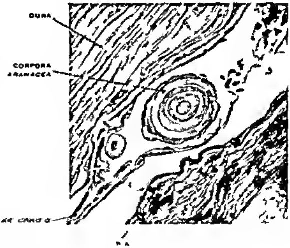


Fig 16[illegible]—Corpora Aranacea in Arachnoid

The Arachnoid is a very thin membrane some 10 μ in thickness which consists of a central core of for the most part non nucleated collagenous tissue which is covered on either side by endothelium

The outer endothelium (i e that facing the dura) has a tendency to proliferate and become several layers thick It may even form endothelial pearls (*corpora aranacea*) (Fig 16[illegible])

[1] The subdural space often appears in ordinary microscopic section to be as large as the sub arachnoid (Fig 45) This is an artefact The subdural space here is capillary only as it is in the cranial cavity

From it numerous trabeculæ pass to the pia and anastomosing amongst themselves form a network in the subarachnoid space. Each trabecula consists of a central core of collagenous tissue surrounded by endothelium.

The Pia has a structure similar to the dura, only here the peripheral fibres tend to be circular.

Also the pia sends numerous septa into the optic nerve which divide its fibres into separate bundles (Fig. 84).

Traced anteriorly

The Dura becomes continuous with the outer two-thirds of the sclera usually without line of demarcation.

The Arachnoid ends on a level with the posterior part of the lamina cribrosa by becoming continuous with the sclera.

The Pia, turning outwards, also becomes continuous for the most part with

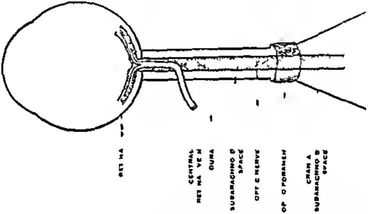


FIG. 114.—DIAGRAM TO SHOW THE CONTINUITY BETWEEN THE CRANIAL SUBARACHNOID SPACE AND THAT AROUND THE OPTIC NERVE.

Note how the central vessels cross the space and may be compressed if the intracranial pressure be raised and thus produce papillœdema.

the sclera, but some fibres run into the choroid and some into the border tissue round the optic nerve.

The Subarachnoid Space ends in a cul de sac which lies in the sclera and whose anterior extremity reaches the back of the lamina cribrosa. It is widest anteriorly where the optic nerve is thinnest, and in a temporally directed scleral canal is wider on the nasal side.

It will thus be seen that for the most part the dura is connected to the pia by trabeculæ.[1] In most places these tear easily, so that the dura can be made to slide backwards and forwards on the pia. (Normally in the movements of the eye a slight amount of this sliding probably also takes place.)

[1] See Schwalbe, *Archiv fur mikroskop. Anat.*, 1870, Bd. 6.

Close to the eyeball however, the connection is stronger, and again in the optic canal the relationships of the various sheaths are of special interest

Here the dura is so firmly united to the optic nerve that it is impossible to separate them Only on the under aspect of the nerve is the connection as elsewhere

Thus only in the lower part is there a subarachnoid space which communicates on the one hand with the intracranial subarachnoid space, and on the other with the subarachnoid space round the remaining portion of the optic nerve

It is thus quite easily seen how a frontal tumour, pressing on the optic nerve from above could obliterate this communication and give rise to optic atrophy rather than papillœdema

This close union of the dura to the optic nerve is of importance, as the dura is itself firmly united to the bone forming the upper aspect of the canal

This clearly forms a point of fixation for the nerve which might otherwise be pushed into the cranium and thus be liable to injury in the canal (Schwalbe)

Structure of the Optic Nerve —The optic nerve consists essentially of visual fibres, which are the axones of the ganglion cells of the retina, and which will make a cell station in the external geniculate body after partially decussating in the chiasma (Fig 61)

But the optic nerve contains other fibres besides the visual

1 Pupillary fibres
2 Retino motor fibres from the brain to the retina (Fig 61)
3 Probably inter retinal fibres = commissural fibres between the two retinæ
4 Possibly trophic fibres

If we examine a cross section of the nerve, we find it is immediately surrounded by the pial sheath, and from this septa pass into the nerve and divide it into numerous (800–1,200) bundles (Fig 84)

The framework of the optic nerve is most dense in its most vascular portion, i e distal to the entrance of the central vessels and in the optic canal Near the chiasma there is a well marked septum which passes obliquely from above downwards and inwards to or just beyond the centre of the nerve This as well as the trabeculæ disappears in the chiasma There are no trabeculæ in the optic tracts

The Septa —*To understand the structure of the septa it is best to study their* development The developing optic nerve has a glial membrane surrounding it As the septal vessels carrying with them connective tissue cells invade the nerve at about the fourth month of intrauterine life they invaginate this membrane Thus each septum has a vessel in its centre, this is surrounded by connective tissue which in turn is bounded by neuroglia (Fig 164) The vessels enter the nerve transversely (radially) divide dichotomously repeatedly and, anastomosing with neighbouring vessels form a vascular net which reaches the centre of the nerve or the central vessels The septal vessels also send branches anteriorly and posteriorly between the nerve bundles

The septa pass into the cross section of the nerve radially. There are some six to nine very thick septa and between these a great number of thinner septa 1 mm or less apart. These, as did the blood vessels, divide repeatedly and dichotomously, and anastomosing with neighbouring septa form meshes which divide the nerve into bundles. The spaces formed by the septa are round or polyhedral, but the angles are always rounded in contradistinction to that seen in most animals.

The antero posterior branches of the septal vessels anastomose with each other and with the transverse branches to form a longitudinal vascular net around each nerve bundle. The septa formed on this scaffolding therefore surround the bundles in the form of a tube or cylinder. This tube, however, is not closed, for it is perforated to allow neighbouring nerve bundles to communicate with each other.

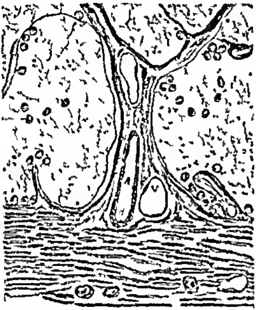


Fig. 164.—Transverse Section of a Septum of the Optic Nerve (Zenker. Mallory's triple stain) to show that each Septum contains a Vessel (or Vessels). Around this is Connective Tissue and then a Glial Membrane.

(Author's preparation.)

It thus comes about that in an antero posterior section of the optic nerve the longitudinal septa are not continuous. The gaps in each septum correspond to the holes in the cylinder and are normally occupied by columns of glial cells (Fig. 159).

On transverse section also incomplete septa are seen. They are completed by glia (Fig. 164).

The cross section of each septum may be flattened or quadrilateral or prismatic, depending on the position of the septal vessels.

The structure of each trabecula is as follows:

In the centre is a vessel which in the case of the larger septa has a well marked muscularis and elastica. Around this is a variable amount of loose connective tissue. This in turn is surrounded by dense connective tissue. Around this again are glial fibres and glial nuclei (Fig. 164).

The septa are continuous with the pia and this is the reason why the latter is only separated from the nerve with difficulty.

Generally speaking the septa are best developed where most movement is liable to take place that is directly behind the globe and just in front of the optic foramen but with reference to the septa we may divide the optic nerve into five parts (Behr)

1 The anterior 1 cm shows a strong development of the septa with marked transverse fibres

2 The middle intraorbital portion with narrower septa and only slight transverse bundles

3 The posterior part of the intraorbital portion is like the anterior but the transverse bundles are more marked

4 The anterior part of the intracranial portion while generally the septa

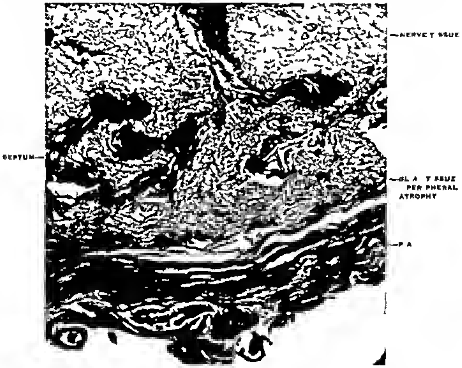


FIG 165—TRANSVERSE SECTION OF THE OPTIC NERVE (ZENKER MALLORY'S TRIPLE STAIN) TO SHOW FUCHS PERIPHERAL ATROPHY OR GLIAL MANTLE

Note that this is normal glial tissue This stains much more densely (redder with the triple stain) than the nerve tissue The difference in texture can also be seen clearly

are regularly distributed there is here a great difference between the peripheral and the axial portions where the papillo macular bundle is placed The septa are not only thinner but less numerous so that larger bundles are enclosed by them Probably the vascular arrangements therefore of the papillo macular bundle are not so good as those of the other fibres (Behr)

5. In front of the chiasma the connective tissue septa disappear entirely and only glial septa remain.

Lining the pia is the "glial mantle" of Fuchs, which consists of a layer of glial tissue (Fig. 165). This also sends prolongations into the nerve, which not only line the septa, but also pass into the nerve bundles themselves. Glial cells lie scattered along the glial prolongations. The glial mantle varies in thickness but is generally quite thin. It is greatly thickened, however, in the floor of the third ventricle and again just behind the optic canal. This latter thickening lies at the upper and outer part of the nerve.

From it an important oblique, somewhat triangular, glial (previously described as pial) septum runs from above downwards and inwards to end in a point a little in front of the chiasma. It sends spidery processes into the nerve which join with the trabeculæ. The septum divides the nerve fibres into a ventro-medial and a dorso-lateral portion, the former being the fibres which will cross over to the other side and the latter forming the temporal uncrossed bundle.

The glial septum marks the end of the septal system of the optic nerve, which are therefore not found in the terminal part of the nerve. The absence of septa here enables the unhindered course of those (anterior) loops formed by fibres which come from the opposite optic nerve (Wilbrand) (see p. 254 and Fig. 173 E).

Also, the end of the glial septum marks the actual beginning of the physiological chiasma, i.e. it marks the position where the crossed fibres first separate from the uncrossed, which therefore takes place above the macroscopic chiasma.

Sometimes spaces are seen between the septa and the nerve bundles. These are held to be lymphatic spaces, since they fill when the optic nerve is injected as in the experiments of Schwalbe and Key and Retzius.

But Salzmann holds that they are artefacts,[1] and has never been able to make out an endothelial lining.

The Fibres of the optic nerve are of *two kinds*, fine and coarse, or more correctly fine and very fine, for they vary from 2 to 10 μ, whereas the diameter of a fibre from an ordinary peripheral sensory nerve is 20 μ.

The fibres have a medullary sheath, but no sheath of Schwann (neurilemma). They thus resemble the fibres of the central nervous system. *Hence probably, the reason why they do not regenerate when cut.* According to Ingvar, the pupillary fibres are older phylogenetically, are non-medullated and run in the periphery of the nerve. Not infrequently one finds in the optic nerve areas which resemble corpora amylacea.

The Optic Chiasma

The Optic Chiasma is a flattened, oblong band some 12 mm. in its transverse

[1] Not infrequently one sees nodes of ill-staining tissue in the optic nerve. These constitute the fleck form degeneration of Siegrist and are most probably artefacts due to bruising in removing the nerve post-mortem. Corpora Amylacea are highly refractile bodies, often showing concentric lamellation, found among the nerve fibres or in the glial tissues most commonly in old people or in atrophic eyes.

diameter and 8 mm from before backwards Clothed in pia it lies obliquely in the cisterna basalis over the pituitary fossa, above and behind the so called optic groove on the sphenoid bone (Fig 130)

In the majority [1] of cases (79 per cent) it lies above the pituitary fossa in such a way that a part of the fossa shows in front of it Only in 5 per cent does it lie in the (so-called) optic groove

In 4 per cent it lies right behind the fossa, and in 12 per cent a greater part of the fossa shows behind the chiasma than in front

The chiasma is not in contact with the diaphragma sellæ, but is separated from it by 5 to 10 mm It follows from this that a portion of the cisterna basalis lies deep to the chiasma (Fig 129)

Relations.—*In front* are the anterior cerebral arteries and their anterior communicating branch

Laterally, the internal carotid artery, as it passes upwards, after having pierced the roof of the cavernous sinus, lies on each side in contact with the chiasma in the angle between optic nerve and tract (Fig 175) Laterally, too, is the anterior perforated substance

Behind is the tuber cinereum, to which the stalk (infundibulum) of the pituitary body is attached (Fig 175)

Above is the third ventricle, in the floor of which the chiasma makes a prominence which is continuous anteriorly with the lamina terminalis

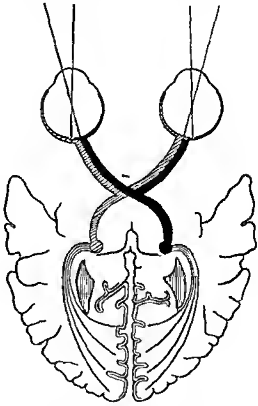


FIG 166 —DIAGRAM OF THE VISUAL NERVE PATH SHOWING THE LINES OF PROJECTION OF THE FIXATION AREA AND BLIND SPOT

(*After Traquair*)

THE OPTIC TRACTS

Each Optic Tract is a cylindrical band which runs outwards and backwards from the postero lateral angle of the chiasma, between the tuber cinereum and the anterior perforated substance

Becoming flattened, it is closely applied to the upper part of the anterior surface of the cerebral peduncle Below and parallel to it runs the posterior cerebral artery (Figs 174, 175)

Here it is divided by a shallow furrow in to its so-called medial and lateral roots

The Medial Root is the Commissure of Gudden which has nothing to do with

[1] Schweinitz G de *Trans Ophth Soc U K*, 1923 xliii p 12

vision It connects the two internal geniculate bodies by passing to the inner side of each optic tract and behind the chiasma It is probably an auditory commissure

The Lateral Root, the true visual portion spreads over the external geniculate body, and for the most part (at least 90 per cent) ends in it (Fig 137)

In the first portion of its course the optic tract runs above the diaphragma

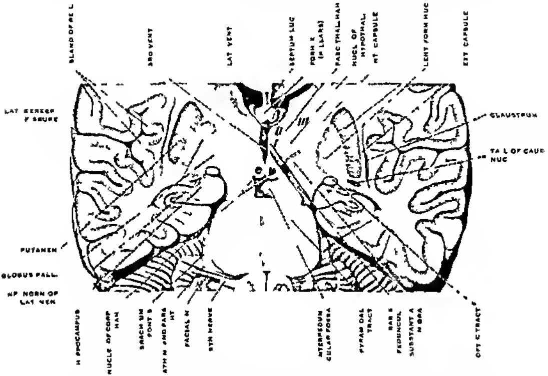


FIG 138 A SECTION OF THE BRAIN IN THE PLANE OF THE BRAIN STEM FROM IN FRONT

On the left the section through the hemisphere is somewhat dorsal to that on the right I II and III indicate the anterior medial and lateral nuclei of the thalamus

(*From Sobotta*)

sellæ and crosses the third nerve from without inwards Above is the posterior part of the anterior perforated substance and the floor of the third ventricle while medially is the tuber cinereum

In the middle portion of its course the tract lies between the uncus (which has the gasserian ganglion on its under surface) and the crus cerebri Here it crosses the pyramidal tract which occupies the middle segment of the crus Also near the pyramid just dorsal to the substantia nigra is the lateral fillet carrying sensory fibres It thus comes about that a single lesion here can affect vision and also the great motor and sensory tracts (As will be seen later the optic radiations also cross and come into close relation with motor and sensory tracts in the posterior

part of the internal capsule, so that here also a single lesion may affect all three)

In the posterior part of its course the optic tract lies in the depths of the hippocampal fissure close to the medial part of the roof of the inferior horn of the lateral ventricle It has the globus pallidus above the internal capsule medially, and the hippocampus below (Fig 167)

It used to be taught that the optic tract ended in the so called three primary or lower visual centres, namely, the external geniculate body, the pulvinar of the thalamus and the superior corpus quadrigeminum Now, while it is still disputed whether any *visual fibres* do go to the thalamus, all are agreed that none reach the superior colliculus The *pupillary fibres* branch off from the true visual portion of the tract, to run in the superior brachium towards but probably not reaching, the superior colliculus (Fig 180) The fibres that do reach the superior colliculus possibly subserve photostatic reflexes

There are other tracts besides that of Gudden which run with the optic tract but do not definitely belong to the visual apparatus

(*a*) **The (Superior) Commissure of Meynert** runs a similar course to that of Gudden It rises in a nucleus situated between the chiasma and third ventricle Its fibres end in the subthalamic region

(*b*) **The Transverse Peduncular Tract** arises from the optic tract where it enters the mid brain passes round the ventral aspect of the cerebral peduncle to enter the brain close to the exit of the oculo motor nerve This tract is better marked in the lower animals than in man in whom it is found in only 30 per cent of cases It is said to atrophy when the eye is enucleated

(*c*) **The Tract of Darkschewitsch** passes from the optic tract to the ganglion habenulæ then through the posterior commissure to the oculo motor nucleus Darkschewitsch thought it carried pupillary impulses but this is doubtful

The External or Lateral Geniculate Body

The External Geniculate Body appears at the posterior end of the optic tract, that is, on the postero lateral aspect of the mid brain as a small flattened ovoid elevation grooved on its postero inferior surface, and enveloped dorsally by the projecting pulvinar which is the posterior extremity of the thalamus The groove is called the hilum

The geniculate body is so placed that its dorso lateral portion is invisible, being enfolded by the pulvinar and thus is only seen in vertical and horizontal sections of the region (Fig 168)

Von Monakov divides it into three parts

(1) The antero inferior portion which receives the optic tract.

(2) The hilum

(3) The lateral portion or spur

According to Pfeifer the external geniculate body has the shape of a Moorish saddle markedly raised posteriorly

On coronal section the external geniculate body has the shape of an inverted heart On horizontal section it is shown to be related anteriorly with the optic tract which ends therein laterally with the retro lenticular portion of the

internal capsule, medially with the medial geniculate body, posteriorly with the hippocampal convolution and postero laterally with the sphenoidal horn of the lateral ventricle. At a higher level the external geniculate body is in relation with the pulvinar which it penetrates. Here it has anteriorly the pregeniculate grey matter flanked anteriorly by the temporo pontine fibres of Turck and the posterior portion of the internal capsule, laterally the area of Wernicke (see

Fig 168.—Para-sagittal (Vertical) Section of the Brain.
Showing optic tract dividing to form capsule to external geniculate body, also its relation to the internal capsule.
(After Ehrenritter, slightly modified.)

below) and medially the medial geniculate body.

Structure.—On section it is seen to consist of alternating white and grey areas. The white areas are formed by the medullated fibres of the optic tract, while in the grey areas are the nuclei in which these terminate and from which arises the new relay of visual fibres forming the optic radiations.

On sagittal section it is seen that the fibres of the optic tract divide into two layers (Fig. 168). The inferior of these forms the white layer of the hilum, the superior forms the dorsal portion of the saddle. Between these laminae which form the capsule of the external geniculate body are alternating layers of myelinated fibres and cells which give the body its characteristic appearance (see also p. 356).

From the dorsal portion of the external geniculate body pass a mass of fibres (which form its peduncle) into the area of Wernicke. This is a small region of myelinated fibres enclosed by the thalamus medially, the internal capsule laterally and the external geniculate body posteriorly. The main constituents of the area of Wernicke are the optic radiations. It also contains the vertical temporo thalamic fibres of Arnold.

The external geniculate body is connected to the superior colliculus by a slender band called the superior brachium (Figs. 137, 174).

The Superior Colliculi

The Superior Colliculi are small rounded elevations situated on the dorsal aspect of the mid brain. They are separated from each other by an antero posterior groove in which lies the pineal body, while a transverse groove comes between them and the inferior colliculi which lie below (Fig 137). Above each superior colliculus is the thalamus. The superior colliculus receives no visual fibres from the optic tract. The fibres it does receive most probably subserve photostatic reflexes. It is doubtful whether any pupillary fibres reach it.

Structure —The surface of the superior colliculus is covered by a thin stratum of *white* fibres (*the stratum zonale*) the majority of which are derived from the optic tract. Beneath this is a layer of *grey* matter (*the stratum cinereum*) which resembles a cap and is thicker in the centre than at the margins. It consists of numerous small multipolar nerve cells embedded in a fine network of nerve fibres. Deep to this again is the *stratum opticum* consisting mainly of fibres in which are embedded large multipolar nerve cells.

The fourth layer *or stratum lemnisci* consists mainly of fibres derived from the lemniscus or fillet and *stratum opticum* in which are embedded large multipolar nerve cells.

Afferent Fibres —(1) From the optic tract via the superior brachium, which runs from the lateral geniculate body to the superior colliculus.

(2) From the occipital cortex via the optic radiations (cortico fugal fibres) to the external geniculate body, and thence via the superior brachium.

(3) From the mesial fillet putting it into relation with the sensory fibres of the cord and medulla.

Efferent Fibres —Of the fibres which arise from cells of the grey matter some cross to the superior colliculus of the opposite side, many after undergoing decussation in the *fountain decussation of Meynert* make connection with the oculo motor nuclei and form the tecto spinal tract which puts it in relation with the spinal nerves.

No fibres pass from the superior colliculus to the cortex, i e it has no cortical projection.

The Thalamus

The thalami are two large ovoid ganglionic masses situated above the crura cerebri on either side of the third ventricle and reaching for some distance behind that cavity. Each measures about 1½ in (3 cm) in length.

The anterior extremity of the thalamus is narrow, lies close to the mid line and forms the posterior boundary of the foramen of Monro.

The posterior extremity is expanded and overlaps the superior corpus quadrigeminum. Medially it presents a well marked angular prominence the posterior tubercle or *pulvinar* which is continued laterally with but a slight line of demarca

tion into *the external geniculate body* Beneath the pulvinar, but separated from it by the superior brachium, is *the medial geniculate body* (Fig 174)

Laterally the thalamus is separated from the *lenticular nucleus* of the *corpus striatum* by the posterior part of the *internal capsule*

It was generally held that the pulvinar of the thalamus was a relay station for the visual fibres on their way to the cortex As the result of the work of Brouwer and Zeeman (1926), Minkowski (1913), and Henschen (1924) it would appear that the pulvinar is not one of the "lower visual centres"

The external geniculate body is, however, connected to the thalamus by the "tractus geniculo thalamicus," in regard to which I would quote from Professor Elliot Smith's Bowman Lecture (1928)

"Only in mammal does the lateral geniculate body emit an optic radiation which passes to the cortex What becomes of the optic impulses to the lateral geniculate body in animals in which there are no optic radiations? It seems that the thalamus is the part of the brain which is responsible for the affective appreciation of experience, and therefore in the last resort determines the animal's behaviour It is essentially the leading segment of the brain The cerebral hemisphere is primarily a receptive apparatus for olfactory impressions The part of the brain which determines what an animal will do in response to stimuli is the thalamus, it receives impulses coming from the skin muscles and joints, and from every part of the body, which make the animal aware of what is happening in the world outside the surface of its skin and determines its affective state It seems inconceivable that the lateral geniculate body which receives optic impressions and is actually spread out on the surface of the thalamus should not participate in this function of awareness It is obvious to those who study the behaviour of fish, amphibian, reptile, bird or mammal that visual experience enters consciousness and plays a large part in determining the animal's behaviour Therefore it seemed inconceivable that there should be no connection between geniculate body and the part of the brain which is responsible, in the last resort, for the shaping of the animal's feelings and determining what its behaviour shall be Yet on looking through the literature I could find only three lines of reference to such a connection it is in a paper by Dr Chiao Tsai published three years ago He called attention to the fact that there was a small fibre tract connecting the lateral geniculate body with the sensory nuclei of the thalamus But he did not consider it important enough to give a name to the bundle

Prof Le Gros Clark lent me sections of the brain of the jumping shrew (*Macroscelides*), which display the connecting bundle—which might be called 'tractus geniculo thalamicus'—as a large bundle of fibres linking up the lateral geniculate body with the rest of the thalamus

"A most striking demonstration of such a connecting bundle was given many years ago by Ramon y Cajal In the preparation of the brain of a small mammal stained by the Golgi method and cut in horizontal section a thalamic nucleus is seen receiving fibres both from the medial lemniscus and from the lateral geniculate body But neither in the drawing (of which this fibre tract is the most obtrusive feature) nor in the text is any reference made to it Such a centre for correlating ocular and articular impulses may represent the germ of that swelling which becomes highly developed in the thalamus of man and is known as the pulvinar It is connected with the angular gyrus, and is supposed by some authorities to be concerned with stereognosis Clinical observers, such as Winkler, of Utrecht have been impressed with the possibility of the blending in the thalamus of impulses from the eyes with those coming from the joints and skin"

The Optic Radiations

The Optic Radiations (of Gratiolet) **or geniculo-calcarine pathway**, that is the fresh relay of fibres that carry the visual impulses to the occipital lobe, arise in the external geniculate body (and possibly, as some hold, from the pulvinar of the thalamus as well).

They pass backwards in the posterior part of the internal capsule, then lateral to the posterior horn of the lateral ventricle. The ventral part of the radiations runs forwards into the temporal lobe before it sweeps backwards to join the remaining portions (Fig 170) (*Injury to this ventral portion causes a superior quadrantic Hemianopia*)

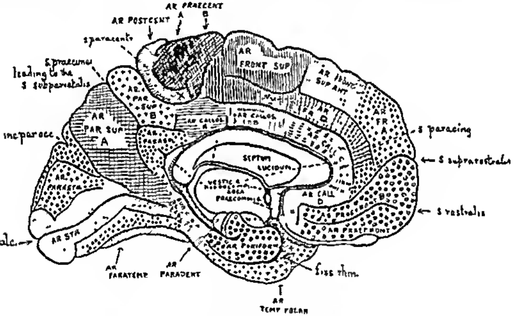


Fig 169 — Topographical Plans of the Cortical Areas (Medial Surface)
(Elliot Smith)

The optic radiations end in the occipital lobe in an extensive area of thin cortex[1] (1·5 mm. or less in thickness), in which is found the distinctive white line or stria first described by Gennari in 1776.

Apart from these cortico-petal fibres the optic radiations also contain fibres that pass from the cortex to the external geniculate body, the thalamus, the superior corpus quadrigeminum, and oculo-motor nuclei.

The Visual Cortical Area or Area Striata

The visual cortex is situated for the most part on the medial aspect of the occipital lobe in relation to the calcarine fissure. A *variable* portion, however,

[1] See G. Elliot Smith, *Journ. Anat and Phys.*, 1907, xl, 200.

extends on to the lateral aspect of the occipital pole, and is limited there by a semilunar sulcus, the sulcus lunatus (of Elliot Smith[1]) or Affenspalte.

The visual cortex is characterised by the distinguishing *white line* or stria,[2] of Gennari, which is visible to the naked eye. Hence the region is called the *area striata*. The stria of Gennari is formed in the fourth layer of the cortex by the medullated fibres of the optic radiation running parallel with the surface of the cortex before they terminate in it.

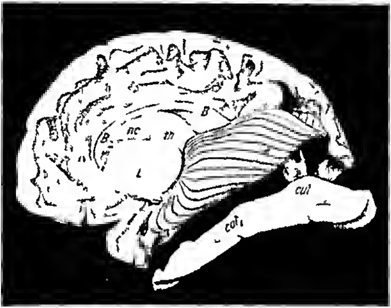


Fig. 170.—The Form and Position of the Geniculo-calcarine Pathway.

K = temporal bend of optic fibres. B = corpus callosum. L = lenticular nucleus. *nc* = nucleus caudatus. *th* = thalamus. *col* = grey matter of collateral fissure. *cul* = highest level of grey matter of collateral fissure.

(From Pfeifer in the Kur. d. Handbuch, 1930.)

The calcarine fissure is divided at the point where the parieto-occipital fissure cuts it into anterior and posterior parts, and while there is visual cortex on *both sides* of the posterior portion, the stria is only found *below* the anterior (Fig. 169).

The upper boundary of the area striata is the sulcus cunei, which lies in the cuneus or region between the parieto-occipital and calcarine fissures.

The lower boundary is the sulcus lingualis.

If the whole visual cortex be excised and flattened out, it will be found to present the form of an elongated ovoid some 3,000 sq. mm. in area. The narrow end of the ovoid lies close behind and below the splenium of the corpus callosum.

[1] See G. Elliot Smith, *Journ. Anat. and Phys.*, 1907, xli, 200.

[2] Best seen on sectioning a fresh brain.

(see Fig. 137), while the rest of it extends backwards from this point to the occipital pole and beyond it on to its lateral aspect.

At about the sixth month of intrauterine life the area becomes folded along

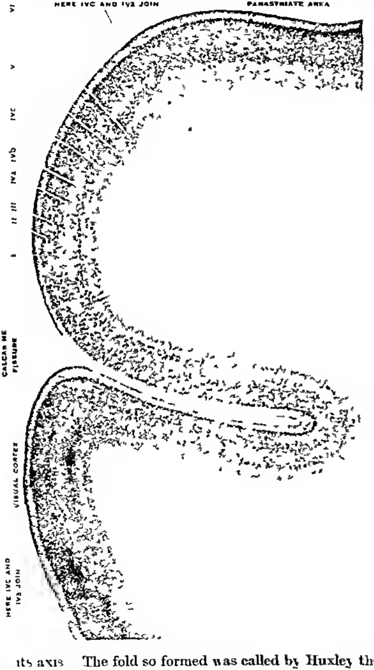


FIG. 171.—SECTION OF THE VISUAL CORTEX.

Lamination of the Visual Cortex.

According to Brodmann's classification there are six layers (*Journ. f. Psychol.*, 1903, Bd. II, p. 137).

I. *The Lamina Zonalis* is the clear superficial layer. Next comes a thick dark layer which really consists of three portions—layers II, III and IVa.

II. *The Outer Granular Layer* is the outermost portion of the thick dark layer.

III. *The Lamina Pyramidalis* is the middle portion of this layer.

IVa. *The Inner Granular Layer* is the innermost portion of the thick dark layer.

IVb. *The Inner Granular Layer* (the stria of Gennari) is the clear layer that follows.

IVc. *The Inner Granular Layer* is the next dark layer.

V. *The Ganglion Layer* is the clear layer that follows.

VI. *The Lamina Multiformis* is the innermost dark layer.

Note that the stria of Gennari corresponds to IV*b* and that it is cut off from the parastriate area by the blending of IV*a* and IV*c*.

(*After Vogt, Journ. f. Psychologie*, 1904.)

its axis. The fold so formed was called by Huxley the calcarine fissure, because its anterior part produces the prominence of the calcar avis in the interior of the posterior horn of the lateral ventricle.

The anterior part of the fissure is much deeper, more constant in form and position, and more precocious in development than the posterior. Phylogenetically, also, it is the older (Elliot Smith).

The calcarine fissure may be continued on to the lateral aspect of the occipital pole as the *sulcus calcarinus lateralis*.

As stated above, the area striata usually extends on to the lateral surface of

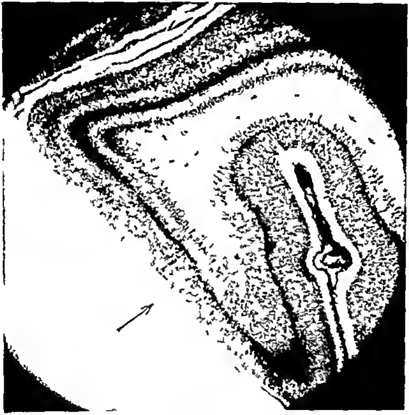


FIG. 172.—SAGITTAL SECTION THROUGH THE BRAIN OF A NEW-BORN CHILD. LOWER LIP OF THE CALCARINE FISSURE.

Note the sudden termination of the stria of Gennari. The area parastriata is to the right.
(From Pfeifer in the Kurzes Handbuch.)

the occipital lobe, where it is bounded by the sulcus lunatus at or near which the white line of Gennari ends.

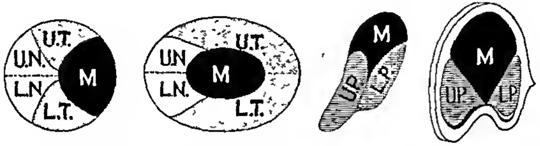
The position of the sulcus lunatus or Affenspalte is very variable, and depends on the development of the parietal and temporal association areas. If well developed these may push the sulcus lunatus and thus the visual area on to the medial aspect of the hemisphere, while in some brains it may be a large sulcus well on to the lateral aspect of the brain and resembling that found in apes (thus

Affenspalte). *Hence the reason why, in bullet wounds of the postero-lateral aspect of the brain, some individuals show practically no visual defect, while others show a great deal.*

The area striata is the true visual cortex, i.e. the true receptive centre for visual impressions. Around it is the parastriate area, and around this again the peristriate area.

These are the visual association areas (visuo-psychic or visual memory centres).

Injury to the *angular gyrus,* which caps the curled-up posterior end of the middle temporal sulcus, is said to lead to word blindness, i e. the patient can see words but cannot grasp their meaning Stimulation of the angular gyrus also is said to produce conjugate deviation of the eyes to the opposite side.



A In the optic nerve (distal). *B In the optic nerve* (proximal). *C. In the optic* tract. *D In the lateral* geniculate body.

The crescents below U.P. and L P. are the uniocular fibres

FIG. 173—DISTRIBUTION OF THE VISUAL FIBRES.

M = macular U.T. = upper temporal L.T. = lower temporal. U.N = upper nasal. L N. = lower nasal. U P. = upper peripheral L P. = lower peripheral.

(After Brouwer and Zeeman)

(Note that in Fig. D, Le Gros Clark and Penman hold that the macular area only occupies the posterior two thirds of the nucleus)

The motor centre for eye movements is in the posterior part of the middle *frontal gyrus.*

Stimulation of this area causes conjugate deviation of the head and eyes to the opposite side.

Connections of the Visual Cortex.

(*a*) With the opposite visual cortex by commissural fibres which run in the splenium of the corpus callosum.

(*b*) With the visual memory and word centres.

(*c*) With the auditory and speech centres by association fibres.

(*d*) With the lower visual centres.

(*e*) With the oculo-motor nuclei and other motor nuclei by descending fibres which run in the optic radiations.

Localisation in the Visual Paths[1]

(*a*) **In the Retina.**—The nerve fibres converge towards the disc. On the temporal side is the important papillo macular bundle. There is no overlap between the upper and lower halves of the fibres of the peripheral parts of the retina (Fig 68).

(*b*) **In the Optic Nerve.**—(1) *In the distal portion* (Fig 173 A) —Behind the eye the peripheral fibres are distributed exactly as in the retina, those from the temporal side are lateral in the nerve, those from the nasal side medial. The macular fibres, which constitute almost one-third of the whole nerve (whereas the macular area is only one twentieth of that of the retina), are laterally placed in the nerve, occupying a wedge shaped area, but as we approach the chiasma they insinuate themselves among the peripheral fibres, so that (2) *near the chiasma* they are centrally placed (Fig 173, B).

(*c*)[2] **In the Chiasma** (Fig 173, E) —The *nasal fibres*, constituting about three quarters of all the fibres, cross over to run in the optic tract of the opposite side. But they do not do this by the shortest route, i e along the diagonals.

In the terminal part of the optic nerve the nasal fibres, which hitherto have kept to an orderly arrangement and run parallel with the optic nerve, spread out so that in a horizontal section they occupy the whole width of the nerve and anterior portion of the lateral part of the chiasma.

The most medial of these representing the fibres from the lower and medial quadrant of the retina bend inwards into the anterior portion of the chiasma and after decussating cross over to the opposite side. The fibres that lie most anterior in the chiasma now form loops convex forwards in the terminal part of the opposite optic nerve and then having reached the temporal border pass backwards to the medial and lower part of the tract. It is probable that these fibres i e those coming from the lower and inner quadrant of the retina, in crossing over in the chiasma lie next its under surface i e nearest the pituitary body, for they are first affected in tumours of this body as shown by the early loss of the upper temporal field. The *anterior loops* are crossed at right angles by those fibres in the optic nerve which are still running parallel to its axis and thus is produced a characteristic basketwork of interlacing fibres (Korbgeflecht of Wilbrand) in the terminal part of the nerve.

The upper medial fibres coming from the upper and inner quadrant of the retina pass to the lateral side in the terminal portion of the nerve and mingle with the uncrossed bundle. They pass backwards here for varying distances. The most lateral ones actually form loops convex backwards in the beginning of the optic tract before crossing over in the chiasma to the supero medial portion of the tract of the opposite side. The *posterior loops* formed by fibres before their crossing are less prominent than those formed by the crossed medial fibres in the terminal portion of the optic nerve.

[1] See Brouwer and Zeeman   [2] See Wilbrand

The actual decussation takes place in the middle of the chiasma, the anterior fibres crossing each other at more acute angles than the posterior The fibres cross over not only from left to right but from above downwards as well.

The Uncrossed Fibres—Just anterior to the chiasma the uncrossed bundle forms a compact fasciculus which occupies almost the whole of the upper and outer quadrant of the nerve

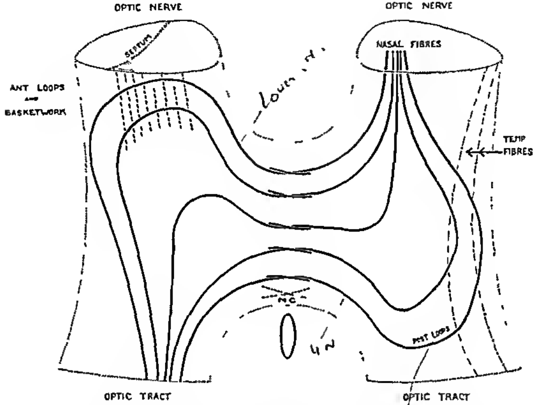


FIG 173. E—THE CROSSING OF THE VISUAL FIBRES IN THE CHIASMA

To avoid confusion only the fibres from one side (except at the actual decussation) are shown M C = macular crossing

These temporal fibres run directly backwards in the lateral portion of the chiasma, those coming from the upper part of the retina being above those from the lower They pass into the tract lying here in the dorso-lateral part

In the chiasma, however, the uncrossed fibres do not form a closed fasciculus, but with them mingle not only the nasal fibres of the same side which have passed laterally before crossing over to the opposite side but also those fibres from the opposite side which form loops in the terminal portion of the optic nerve

This intermixture of fibres is so marked that in a case of unilateral atrophy of the optic nerve horizontal sections of the chiasma do not reveal the position of the uncrossed bundle Only in coronal sections can the atrophic area, i e. the

position of the uncrossed bundle be made out It then appears in the lateral part of the chiasma as a kidney shaped area with its hilum inwards

The Macular Fibres—In the posterior portion of the intracranial optic nerve the papillo macular bundle is central and keeps this position in the anterior part of the lateral portion of the chiasma Then the crossed fibres separate from the uncrossed ones and pass as a bundle obliquely backwards and upwards to decussate with the macular fibres of the opposite side in the most posterior portion of the chiasma, i e in the floor of the recess of the third ventricle Lesions here will therefore cause a central temporal hemianopic scotoma (Wilbrand)

(*d*) **In the Optic Tract**—The macular fibres are first central, then come to lie dorso laterally The fibres from the upper half of the peripheral retina lie dorso medially those from the lower ventro medially (Fig 173, C) The crossed fibres lie on the inferior and inner surface of the tract the uncrossed fibres are more deeply placed

(*e*) **In the External Geniculate Body**—The fibres from the upper part of the retina go to the medial part of the geniculate body those from below to the lateral part The macular area is somewhat wedge shaped involves all the laminæ and is confined to the posterior two thirds of the nucleus broadening towards the caudal pole It is probable that the peripheral areas farther away from the disc are represented in the more anterior levels of the geniculate body (Le Gros Clark and Penman)

(*f*) **Localisation in the Visual Cortex**—The homonymous halves of each retina are represented in the corresponding occipital lobe Thus the right halves of each retina (temporal of the right eye and nasal of the left) will be projected on the right visual cortex

Also the upper and lower portions of the retina will be localised above and below the calcarine fissure respectively

Most observers hold that this applies to the *maculæ* as well as the peripheral retina, i e that the central area has a bilateral representation Lister and Holmes,[1] however as a result of their observations on soldiers with gunshot wounds of the occipital region came to the conclusion that each macula has a unilateral representation They explain the well known phenomenon that in cases of thrombosis of the posterior cerebral artery the resulting homonymous hemianopia spares the macula (the scotoma falling short of the fixation point by 10°) by the fact that the occipital pole is the border line territory between the distribution of the middle and posterior cerebral arteries, and that the former artery will be able to supply the macular area if the latter is blocked

Holmes and Lister also believe that the peripheral retina is represented in the anterior part of the visual cortex, and as we go centrally in the retina the corre

[1] Holmes G *Brit Journ Ophth.*, 1918, 2 353 449 506 *Brit Med Journ.*, 1919 2 Holmes G and Lister W T *Brain* 1916 39 34

See also Carmichael E A *J R Soc Med* Section of Neurology 1937 p 853

sponding area of cortical localisation will be farther back along the calcarine fissure

With regard to the macula they believe that, although there is some degree of localisation of macular representation in the posterior part of the calcarine fissure and extending on to the lateral surface of the occipital pole (Holmes, 1918), at the same time there seems little doubt that the macular fibres are spread

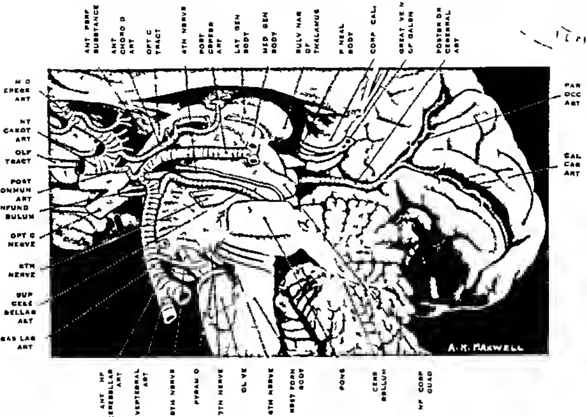


FIG 1"4 —DISSECTION TO SHOW THE BLOOD SUPPLY OF THE OPTIC PATHWAY AND THE RELATIONS OF THE VESSELS TO THE OCULO MOTOR NERVES

From the side

(*Author's preparation.*)

over the whole visual area much like the representation of the hand in the post-central gyrus

With regard to this, however Professor Elliot Smith (*Journ of Anat* 64 1930 p 478) writes In a horizontal section through the posterior pole of a human cerebral hemisphere the area striata distinguished by the presence of the stria of Gennari is seen to undergo a sudden change in character a short distance behind its midpoint The thickness of the stria is reduced and the dark band (which is found on its inner side in the part representing the peripheral retina) disappears The macular cortex begins at this place and extends around the pole on to the lateral surface of the hemisphere to end at the lip of the lunate sulcus As this lateral part of the area striata is much broader than the medial part, exact

measurements reveal the fact that the macular part is at least as extensive as the whole peripheral part It is possible to identify the macular part of the area striata in many

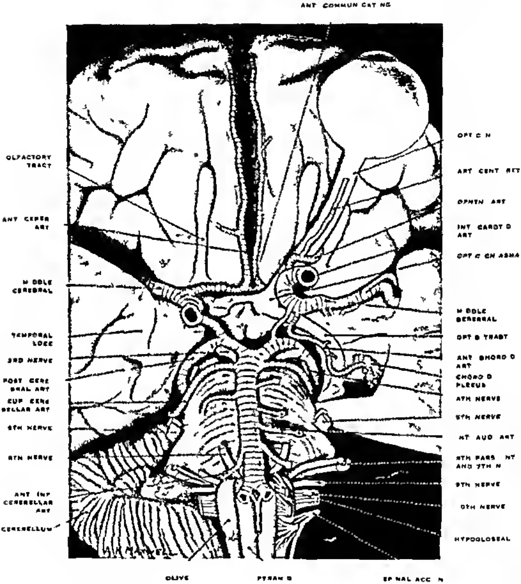


FIG 177 —DISSECTION TO SHOW BLOOD-SUPPLY OF OPTIC PATHWAY AND RELATIONS OF VESSELS TO OCULO MOTOR NERVES

From below

(*Author's preparation.*)

human brains by simple observation of the morphological features of the surface of the cerebral hemisphere Looking at the posterior aspect of the hemisphere three semilunar

sulci—lunatus polaris superior and polaris inferior—may often be seen arranged in a trefoil or shamrock leaf pattern (grouped around the calcarine sulci in the axis of the area striata) The rapid expansion of the lateral part of the area striata to afford cortical representation of the macula is responsible for the formation of three opercula bounded by these three semilunar sulci Hence the presence of this cortical shamrock pattern affords definite evidence of the position and extent of the macular area

The Uniocular Visual Fields

It would appear that the fibres which subserve the uniocular and binocular visual fields run separately

Brouwer and Zeeman found that in the rabbit the binocular field (which in this animal is only 20 degrees) occupies a very small area in the lateral geniculate body while nearly the whole of the remainder is taken by the uniocular

In man it is the other way round

The uniocular field that is the part seen by one eye only, is represented by the *extreme temporal field* *The retinal fibres involved are the most nasal* From here they run to the inner side of the crossed bundle to a small strip on the ventral part of the external geniculate body

In the visual cortex the uniocular field is localised anteriorly in the lower lip of the calcarine fissure

The importance of all this clinically is that it is possible to have a lesion of the optic radiations for instance affecting one field only

The Cortical Oculo motor Centres

1 Frontal
2 Occipital
3 Angular Gyrus

1 The frontal centre lies in the posterior part of the middle frontal gyrus It controls voluntary movements Stimulation of this area results in conjugate deviation of the eyes to the opposite side stimulation above the centre results in conjugate deviation downwards and stimulation below in conjugate deviation upwards

Paralysis of this centre does not stop reflex movements due to labyrinthine or retinal impressions

The path of the fibres from the cortical centre to the oculo motor nuclei is not known but it probably runs with the pyramidal tract There is a complete decussation of fibres of opposite sides (probably in the posterior commissure)

2 The occipital centre probably has to do with the fixation reflex i e with bringing on to the macula the image of an object which has interested' the periphery of the retina Stimulation of the visual area causes conjugate deviation of the eyes

3 Conjugate deviation of the eyes has been produced in animals by stimulation of the angular gyrus but not in man in whom operative removal of the area has not resulted in any oculo motor defect

The blood-supply to these centres comes from the middle cerebral for the frontal and angular gyri and from the posterior cerebral for the occipital centre

The Blood supply of the Visual Pathway

The blood supply of the *retina* has been discussed on p 96

The Blood-supply of the Optic Nerve —The optic nerve an outgrowth from the brain has its vascular supply modelled on that organ The resemblance is great but not absolute for here we have no grey matter and no nerve cells The optic nerve *chiasma and tracts are covered with pia mater identical with that of the brain* Only those portions of the chiasma and tracts adherent to the base of the brain are bare of pia

All the arteries which will eventually supply the nerve tissue do so through the pial network of vessels This network is rich and fine and extends to the back of the globe In the intracranial portion of the nerve it is situated on the surface of the pia, in the orbital portion in its thickness between the longitudinal and circular fibres

As in the case of the cerebral convolutions there are actually two networks one inside the other The outer is the larger and formed of arterioles of fair size, the other, lying within the first consists of vessels so small that a loupe is necessary to see them The network is supplied by arteries which probably anastomose slightly in the network but not before they reach it

When the vessels pass *into* the nerve they take with *them a coat of pia and* also a covering of glia which constitute the septa In fact the distribution of the septa is exactly that of the blood vessels Also the thickness of each septum is proportional to the size of the contained vessel While this is obvious in the orbital portion of the nerve it is more difficult to make out in the tract and chiasma In the most posterior portion of the optic nerve (where the septa gradually disappear) in the chiasma and in the optic tract even the larger vessels are only surrounded by a slight covering of connective tissue which gets less with the smaller vessels and seems to disappear entirely in the capillaries They are however always separated from the nerve tissue by the perivascularis glia

There is a striking contrast between the great vascularity of the pia and the relatively few vessels in the dura (Magitot) The pial network acts as a distributing centre which provides for a regular supply of blood to the nerve As the vessels pass into the nerve in the septa they divide dichotomously as these do and send branches anteriorly and posteriorly

The vessels which join it eventually come from the internal carotid and since the eye has grown out from the brain its vessels have followed it This explains

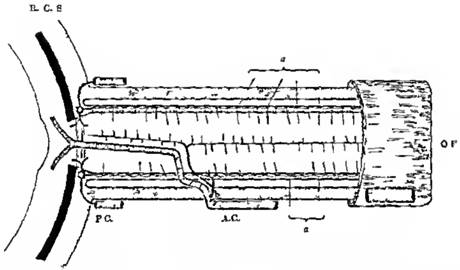


FIG 176 —SCHEMATIC LONGITUDINAL SECTION OF THE OPTIC NERVE TO SHOW ITS BLOOD SUPPLY
A C. Arteria centralis P C Posterior ciliary artery O F Optic foramen R. Retina C Choroid S Sclera a Group (a)

why the vessels to the chiasma are short and those to the globe relatively long (Magitot, *Thèse de Paris* 1908)

The intracranial portion.—As in the case of the chiasma, the principal vessels are the anterior cerebral and the internal carotid—the former for the superior, the latter for the inferior aspects. The ophthalmic artery and the anterior communicating may help. The feeding vessels pass to the pial network and thus into the nerve.

A cross section of the nerve shows that the septal network here has a special

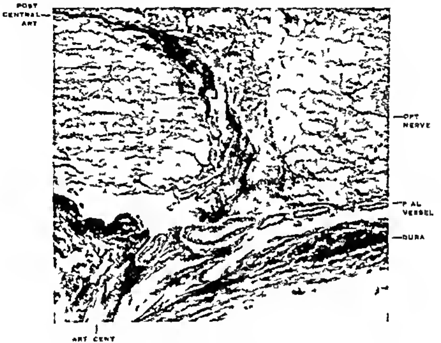


FIG. 1[illegible]A.—LONGITUDINAL SECTION OF THE OPTIC NERVE SHOWING A LARGE BRANCH FROM THE ARTERIA CENTRALIS PASSING FORWARDS IN THE SUBARACHNOID SPACE TO THE PIAL PLEXUS. ALSO A POST CENTRAL ARTERY PASSING BACKWARDS.

(Author's preparation)

appearance—whereas in other parts of the nerve the thickness of the septa is fairly constant, in the axial part of the intracranial portion they are not only thinner but the meshes are wider. Hence smaller vessels supply a large number of nerve fibres. Thus any interference with the blood supply would, according to Behr, affect first and most markedly the central papillo macular bundle.

The whole of the remaining portion of the nerve and also the whole of the globe is supplied by the ophthalmic artery.

The intracanalicular portion is supplied by the ophthalmic, but differs from the orbital portion in that the pial network is relatively poor.

The orbital portion is supplied by two groups of vessels.

(A) Those that pierce the dura behind the entrance of the central vessels

(B) Those that enter the nerve or join the pial network at the site of entry of the central vessels

Group A —In approximately the posterior half of the orbital portion of the optic nerve some six to a dozen small vessels derived from the ophthalmic and its branches (including the arteria centralis), pierce the dura on various aspects but mainly above and at the sides The least pass in from below since this portion is supplied by recurrent branches from Group B

Having pierced the dura these vessels pass across the subarachnoid space either at right angles or obliquely and clothed in a portion of dura and arachnoid as is the central artery in like position reach the pial network

Group B —At about the point where the central artery pierces the dura it

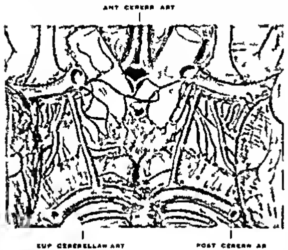


FIG 177 THE INTERPEDUNCULAR SPACE AND CIRCLE OF WILLIS (MODIFIED AFTER JAYLE) SHOWING THE BLOOD SUPPLY TO THE CHIASMA OPTIC NERVE AND TRACT

gives off one or more branches which diminish its diameter by about one third Some of these immediately enter the pia (Fig 176) dividing into branches which go forwards backwards and circularly and joining the pial network send branches into the nerve Others pass into the nerve with the central artery running parallel with it Although extremely well described by Kuhnt in 1879 these important vessels have often been forgotten in subsequent works and this has led to a great deal of confusion To emphasise the fact that they do exist one would suggest the name of central collateral arteries (arteriæ collaterales arteriæ centralis retinæ) (Figs 84 86 176)

One of these vessels larger than the rest runs with the central artery to the lamina cribrosa The collateral vessels send branches into the nerve and hence get narrower as they pass anteriorly At the point where the central artery bends forwards at the centre of the nerve a branch of the collateral artery (not of the central artery itself (Magitot)) passes backwards towards the optic foramen (Fig 176A)

While as we have seen the collateral arteries get finer as we trace them

forwards, the central artery remains much the same size from its point of penetration to its bifurcation. This is due to the fact that, in this portion of its course,

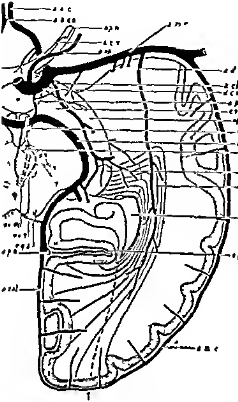


FIG. 178.—TOTAL BLOOD-SUPPLY TO THE VISUAL PATHWAYS, VIEWED FROM THE VENTRAL ASPECT. SEMI-SCHEMATIC (ABBIE)

Note the different sources of supply to the optic radiation. The arrow at the bottom of the figure marks the point of anastomosis between the calcarine and middle cerebral arteries.

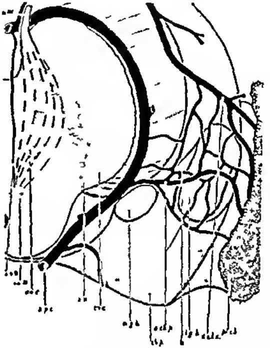


FIG. 179.—THE ARTERIAL NETWORK OVER THE LATERAL GENICULATE BODY (SIMPLIFIED) (ABBIE)

Note its derivation from the anterior and posterior choroidal arteries. The specific end artery from posterior cerebral to the oculo-motor nucleus is indicated.

ABBREVIATIONS EMPLOYED IN THE FIGURES.—a.a.c., anterior cerebral artery; a.a.co., anterior communicating artery; a.b., basilar artery; a.c.i., internal carotid artery; a.c.r., central artery of the retina; a.cal., calcarine artery; a.ch.a., anterior choroidal artery; a.ch.p., posterior choroidal artery; *a.d.op., deep optic branch of the middle cerebral artery*; a.m.c., *middle cerebral artery*; a.n.III, artery to oculo-motor nucleus; a.op., ophthalmic artery; a.p.c., posterior cerebral artery; a.p.co., posterior communicating artery; a.p.o., parieto-occipital artery; b.ol., olfactory bulb; c.a., anterior commissure; c.c., *corpus callosum*; c.q.s., *corpus quadrigeminum superior*; cr.c., *crus cerebri*; f., fornix; h., hilum of lateral geniculate body; h.a., hilar anastomosis; l.g.b., *lateral geniculate body*; m.g.b., *medial geniculate body*; *n.III*, oculo-motor nerve; nu.III, oculo-motor nucleus; nu.r., red nucleus; op.ch., optic chiasma; op.n., optic nerve; op.r., optic radiation; op.t., optic tract; pl.ch., choroidal plexus; po., pons; s.cal., calcarine sulcus; s.lun., lunate sulcus; s.n., *substantia nigra*; s.p.cal., posterior calcarine sulcus; s.p.o., parieto-occipital sulcus; t.p., temporal pole; th.p., *pulvinar thalami*.

the arteria centralis has no branches of any size

The injections by Beauvieux and Ristitch of the arteria centralis *alone* appear to show that the region of the *lamina cribrosa* is supplied by the circle of Zinn only. According to Leber, however, small branches do pass from the arteria centralis into the lamina cribrosa and form a capillary anastomosis with branches coming from the circle of Zinn. My own preparations[1] agree with this latter view (Fig. 87)

The *nerve head* is supplied by the central artery and the circle of Zinn which also sends branches into the neighbouring retina. The number and size of these branches to the retina are variable, but more evident on the temporal side. Here we find all grades up to what is known as a cilio retinal artery (see p. 99)

The Blood-supply of the Chiasma.—The chiasma gets its main blood supply from the anterior cerebrals and internal carotids. The posterior communicatings, which are in relation to its under surface and the anterior choroidals, may help, as also the anterior communicating when it is present.[2] The anterior cerebrals supply most of the superior aspect while the internal carotids are mainly responsible for the under surface. The feeding vessels again pass to the pial network and thence into the chiasma.

The Blood-supply of the Optic Tract.—The optic tract is also supplied through the pial network of vessels. This is continuous anteriorly with that of the chiasma. The feeding vessels come partly from the posterior communicating but mainly from the anterior choroidal artery (Figs. 174, 177, 178)

Generally the latter artery gives several branches to the tract, but the largest of these pass completely through it to enter the base of the brain and supply, among other structures, a portion of the optic radiation.

According to Shellshear these perforating vessels enter the tract between the crossed (which are the older fibres phylogenetically) and the uncrossed fibres. Sometimes they wind round the tract before entering it. (In this case it is thought that pressure on the tract may disturb nutrition by obstructing the arteries rather than by direct pressure on the nerve fibres themselves.) There is considerable mutual interchange between the anterior choroidal artery and the

[1] According to Leber, from the point of entry of the arteria centralis into the optic nerve to its bifurcation it gives off no branches. Hence in this portion of its course it takes no part in the nutrition of the nerve. I subscribed to this view in an article in the *Trans. O. S. U. K.* for 1939. But since writing that paper I have been fortunate in obtaining normal material and thus been able to make serial sections of the lamina cribrosa region. These showed that the arteria centralis does give small branches (Fig. 87) to this region which agrees with Leber's view. These branches, however, do not alter the clinical fact that a block of the artery anywhere in its intraneural course leads to blindness.

[2] Thus it will be seen that if we include the vessels on either side with the median anterior communicating, nine arteries may take part in the supply of the chiasma, or if with Abbie we count the middle cerebrals apart from the internal carotids, eleven arteries. It is thus extremely unlikely that a block of any one vessel will have any marked effect on the visual fibres.

posterior communicating and occasionally one or other predominates to the complete exclusion of its fellow (Abbie)

The Blood-supply of the Lateral Geniculate Body—It used to be held that the lateral geniculate body was supplied by *the posterior cerebral artery and thus* had a different vascular supply from the optic tract This has been shown by Abbie and others to be incorrect In fact in the human while the main supply and especially that to the postero medial aspect comes from the posterior cerebral *the anterior and lateral aspects are supplied almost entirely by the* anterior choroidal artery (Fig 179)

The region of the hilum is nourished through a rich anastomosis from both sources

The anterior choroidal supplies the fibres coming from the inferior homonymous quadrants of the retinæ while the posterior cerebral supplies those coming from the superior homonymous quadrants The intervening region which radiates dorsally from the hilum and contains the macular fibres is supplied by both vessels

Within the lateral geniculate body the terminal twigs from the penetrating vessels end chiefly in the individual cell laminæ some pass beyond into the commencement of the optic radiation (Abbie)

The Optic Radiations—The blood supply falls into three parts (Abbie)

1 While the radiations are passing laterally over the roof of the inferior horn of the lateral ventricle they are supplied by perforating branches of the anterior choroidal artery

2 In their posterior course—lateral to the descending horn of the ventricle—they are supplied by the deep optic branch of the middle cerebral artery which enters the brain through the anterior perforated substance with the lateral striate arteries (Fig 178)

3 As the radiations spread out to reach the striate cortex they are supplied by perforating cortical vessels mainly from the calcarine branch of the posterior cerebral but also from the middle cerebral artery It is said that of these perforating vessels those which supply the radiations are independent of those which supply the cortex

The Visual Cortex is supplied mainly by the posterior cerebral especially via its calcarine branch The middle cerebral helps at the anterior end of the calcarine fissure and on the lateral surface near the posterior pole there is according to Shellshear a fairly well marked anastomosis between posterior and middle cerebrals *which may account for the sparing of the macula in cases of thrombosis of the posterior cerebral*

These vessels form a rich network in the pia from which short branches pass to the grey matter while larger branches pierce this to reach the white matter The latter vessels are practically end arteries communicating by capillaries only Thus we may have localised areas of softening in the white matter

The Blood-supply of the Lower Centres—The roof of the mid brain is supplied from a network of vessels coming from the posterior cerebral and superior cerebellar arteries, but the former vessels provide the main supply to the superior corpora quadrigemina

According to Alezais and D'Astros, the oculo motor and trochlear nuclei are supplied by specific end arteries which arise from the posterior cerebral artery and enter the mid brain through the posterior perforated substance (Fig 177) (Stopford, however, states that these nuclei are supplied from the basilar artery) The abducens nucleus is supplied by a specific end artery which comes from the basilar (Stopford) Very rarely the anterior spinal helps (Shellshear)

The Venous Return is partly by the cortical veins and partly by the internal occipital vein which runs close to the posterior cerebral and has been divided in approaching a pineal tumour (see Harris and Cairns, *Lancet*, 1932 p 3)

These veins are also practically end veins, so long as they are in the brain substance, but intercommunicate in the pia A thrombosis of the veins is less likely to lead to as permanent damage as a corresponding lesion of the artery

Practical Considerations

1 Division of one optic nerve results in blindness of that eye and a dilated pupil which does not react to light directly but does consensually The vision of the other eye is unaffected, its pupil reacts to light directly, but not consensually A glance at the diagram (Fig 180) will make it clear that the reflex can get to the sphincter centre of the affected side, when light is thrown on to the good eye either through the chiasma or through the posterior crossing in the mid brain

The affected pupil will, of course react to convergence, but does not come under the category of the Argyll Robertson pupil (*q v*)

2 Division of the optic chiasma results in bitemporal hemianopia (a condition most commonly, but by no means invariably, seen in pituitary tumours) It abolishes neither the direct nor the consensual pupil reactions

Theoretically, at any rate a modified Wernicke (see later) ought to be present, i e the pupil ought to react when the light falls on the temporal (i e seeing) halves of the retina only Division of the uncrossed fibres of the chiasma gives rise to binasal hemianopia This was noted in a case of Knapp s and was found on post mortem to be due to calcified internal carotid arteries

3 Behind the chiasma complete unilateral division of the visual pathway in any part of its course will result in a contralateral hemianopia, e g if the left pathway is divided there results loss of the right halves (temporal of the right side and nasal of the left) of the visual fields

4 Division of the optic tract produces a contralateral homonymous hemianopia and while it abolishes neither the direct nor the consensual pupil reaction it gives rise to Wernicke s hemiopic pupil reaction i e the pupils do not react when a narrow pencil of light is thrown on the blind halves of the retinæ but do react if it falls on the seeing portions It may not be out of place here to state that owing to the scattering of light by the media of the eye the test is exceedingly difficult to perform

5 Since the pupillary and visual fibres part company in the posterior third of the tract behind this point they are usually affected separately This accounts for the fact that the Wernicke s hemiopic pupil reaction differentiates a tract lesion from a lesion of the visual pathway behind the point of separation

6 Destruction of the external geniculate body gives rise to a contralateral homonymous hemianopia (Henschen Brouwer and Zeeman)

While this is the view which is now becoming generally accepted one must state that von Monakow and others hold that the pulvinar of the thalamus must be involved as well to produce it

7 It is now generally held that destruction of the superior corpora quadrigemina has no effect on vision It is still disputed how many (if any) pupillary fibres reach them Brouwer and Zeeman say that if any do they must be non myelinated and Levinsohn finds that destruction of a superior corpus quadrigeminum in rabbits has no effect on the pupillary reaction

8 Destruction of the optic radiation or visual cortex on one side as occurs in thrombosis of the posterior cerebral artery gives rise to a contralateral homonymous hemianopia The pupils are unaffected and the macula is spared

If the hemianopia is accompanied by hemiplegia or hemianæsthesia the lesion is in the posterior limb of the internal capsule behind the lenticular nucleus

Destruction of that portion of the geniculo calcarine fibres which passes forwards into the temporal lobe results in a superior quadrantic hemianopia

The Medial Longitudinal Bundle

The Medial Longitudinal Bundle is a well marked band of fibres which runs close to the mid line through the mid brain pons and medulla Above it establishes intricate connections with the region immediately above the mesencephalon below it is continuous with the fasciculus anterior proprius of the spinal medulla at the decussation of the pyramids

In the mid brain it lies ventral to the central grey matter and below this directly beneath the floor of the fourth ventricle It is intimately associated with the nuclei of the 3rd 4th and 6th nerves (Figs 130 134 135) The nuclei of the oculo motor and trochlear nerves are closely applied to its medial and dorsal aspect while that of the abducens lies on its lateral side

"It would appear, therefore, that one of the most important functions of the strand is to bind together those nuclei, and thus enable them to act in harmony one with the other"[1]

Thus, in looking to the right, for instance, the external rectus of the right side is enabled to work with the internal rectus of the left.

"The most important element in the medial longitudinal bundle, however, consists of fibres coming from the vestibular nucleus which proceed to the oculomotor group of nuclei of both sides as well as to both accessory nuclei in the medulla oblongata By means of these connections, movements of the fluid in the semicircular canals can reflexly move the eyes and the head

"It is evident that it is a brain tract of high importance from the fact that it is present in all vertebrates and further that its fibres assume their medullary sheaths at an extremely early period In fishes, amphibians, and reptiles it is one of the largest bundles of the brain stem In man, its fibres medullate between the sixth and seventh months of fœtal life and at the same time as the fibres of fasciculus or anterius proprius of the spinal medulla with which it stands in connection"

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CHAPTER VII (*continued*)

THE NERVES

THE INVOLUNTARY NERVOUS SYSTEM [1]

THE involuntary nervous system like the voluntary, has sensory (receptor) connector, and motor (excitor) elements but in the former the excitor elements have left the central nervous system to form the various ganglia The sensory elements have remained in the same position as those of the voluntary system i e in the posterior root ganglia and connect by means of the sensory root with cells of the connector elements which have remained in the central nervous system The connector fibres which are neither sensory nor motor have passed out as white rami communicantes to reach the motor excitor elements which may have wandered to the lateral chain ganglion to a peripheral ganglion such as the ciliary or cœliac or may be motor cells on the wall of the organ supplied (as are seen on the rectum and bladder)

Hence the cell in the lateral chain ganglia is homologous with the anterior horn cell of the somatic system and the lateral horn cell is homologous with the cell of the (intercalated) connector neurone of the somatic system

The collaterals of the sympathetic system make connection with many neurones Hence movements produced by the involuntary nervous system are primitive, i e *en masse* (cf protopathic sensation)

To Summarise

Voluntary System —*Sensory* (*receptor*) neurones both spinal and cranial in the posterior root ganglion or its homologue (e g Gasserian)

Motor (*excitor*) —Neurones in the central nervous system

Connector (*intercalated*) —Neurone also in the central nervous system

Involuntary System —Sensory neurone also in the posterior root ganglion

The motor (excitor) neurone is in the lateral chain ganglia in the peripheral ganglion or in cells on the organ supplied itself

The connector neurone starts in the lateral horn of the dorsal region or its homologue and leaves the cord by the white rami communicantes

They are thus *medullated* pre ganglionic fibres The post ganglionic fibres are non medullated There is only one exception to this in the ciliary ganglion where the post ganglionic fibres are medullated

[1] See Gaskell *The Involuntary Nervous System* 1920

There are four outflows of fine medullated nerves to peripheral motor ganglion cells

1 Prosomatic or mid brain	.	cranial autonomic.
2 Bulbar	. . .	
3 Thoraco-lumbar	.	sympathetic system
4 Sacral (nervi erigentes)	.	sacral autonomic.

1 **The Mid-brain Outflow** of connector fibres probably arises in the nucleus of Edinger Westphal, pass out with the **3rd nerve to the ciliary ganglion**, where they make connection with motor cells From here post ganglionic *medullated* fibres pass in the ciliary nerves to the sphincter pupillæ and ciliary muscles The medullation may be associated with the fact that these muscles are striated in birds Acetyl choline has no effect on this outflow.

There is *reciprocal innervation of antagonists* Thus *stimulation of the 3rd nerve contracts the sphincter and inhibits the dilatator, and likewise the sympathetic is motor to the dilatator, and inhibitor to the sphincter*

2. **The Bulbar Outflow** of connector fibres (corresponding to the white rami of the dorsal region) arises in the nucleus intercalatus of Staderini, which consists of small cells in the dorsal nucleus of the vagus in the floor of the fourth ventricle

The following are the cranial nerves which contain fibres corresponding to white rami and belonging to the bulbar outflow

(1) 7th as the great superficial petrosal from the pars intermedia to Meckel's ganglion by way of the vidian (*q v*) Probably eventually supplies the lacrimal gland

(2) The chorda tympani from the pars intermedia to the submaxillary ganglion, and thence to the submaxillary and sublingual salivary glands

(3) 9th The nervus tympanicus from the glosso pharyngeal to the otic ganglion by way of the small superficial petrosal

(4) 11th The upper rootlets contain fibres which go to the internal branch and join the vagus, while the external branch goes to the sterno mastoid and trapezius

The **Sympathetic Fibres** which pass to the eye are discussed on page 275

The Segmental Value of the Ocular Nerves[1]

In some of the lower vertebrates, especially the elasmobranchs, there are at least nine segments included in the constitution of the head In the higher vertebrates it is difficult to be sure which nerve belongs to which segment, but the following is a commonly accepted view

The 3rd nerve belongs to the 1st head segment *It includes a large-fibred mesial somatic efferent part distributed to the orbital muscles derived from the 1st somite, and a small fibred splanchnic efferent part, passing to the ciliary ganglion*

The lateral somatic efferent fibres are perhaps represented as suggested by Gaskell by the upper (ocular) facial, which is held to be derived from the oculo motor nucleus The ophthalmic division of V appears to be the afferent nerve of this segment In the elasmobranchs, Hoffmann finds the ramus ophthalmicus profundus, which corresponds to our

[1] See Thane in Quain's *Anatomy*, 10th edition

nasal nerve (Ewart) is developed independently of the rest of the 5th, and in close relation to the 1st somite

Gaskell, however, considers that the afferent fibres of the 1st segmental nerve, with their stationary ganglion have undergone degeneration and are now represented only by the vestigial structures on the roots of the 3rd nerve and his view receives support from the observation of Martin that in the early embryo of the cat, the 3rd nerve is provided with a dorsal root which subsequently disappears, a gangliomated dorsal root to the oculo-motor nerve has been described by Kupfer in Ammocoetes and by Froriep in Torpedo

The 4th nerve supplies the superior oblique the muscle of the 2nd somite

The 5th nerve, excluding the ophthalmic division, also belongs to this segment (Hoffmann), of which the motor root is the lateral somatic efferent

The spheno-maxillary and otic ganglia belong to this segment

The 6th 7th, and 8th cranial nerves belong to the 3rd segment

The 6th and 7th are the mesial and lateral somatic efferent respectively The great superficial petrosal and a part of the pars intermedia (that to submaxillary ganglion) constitute the splanchnic efferent while the geniculate ganglion belongs to the splanchnic afferent

The somatic afferent is the auditory, with its acoustic ganglion

The 4th segment is suppressed, possibly it is represented by the pars intermedia

The 9th nerve belongs to the 5th segment

The 10th nerve belongs to the 6th and 7th segments but the mesial somatic afferent of the 7th segment is in the hypoglossal which is composed of the mesial somatic efferent parts of the last three or more cephalic (originally 1st spinal) segmental nerves

CHAPTER VII (*continued*)

THE NERVES

The Path of the Light Reflex [1]

Two main views are expressed with regard to the origin of the light reflex

1 Hess (1908 and 1922) in his experiments with diurnal birds which have yellow oil globules between the inner and outer portions of the rods, and nocturnal birds which have none, showed that visual and pupillary reactions to light stimuli of varying intensity and under different conditions of adaptation ran parallel, and came to the conclusion that the outer portions of the rods are the receptor organs—both for vision and for the light reflex This is the view most widely accepted

2 Schirmer (1894) believed that the light reflex started in the inner nuclear layer especially in the amacrine cells For in diseases of the outer retinal layers, sight is affected much more than the pupil reflex But Von Hippel points out that these cells are absent just in the macular area where the light reflex is most easily obtained

It is probable that the light reflex can be obtained from any portion of the retina up to the ora serrata, and not as Hess thought from the macular area only But it is certainly much more easily elicited when light falls on the central area while strong illumination is necessary to produce it from the peripheral retina

The Afferent Tract —Here again two views are expressed as to whether the visual and pupillary fibres are different or identical That they are probably different is shown by the fact that in certain cases of complete blindness the pupillary reflex was obtained Also as Parsons pointed out, if the fibres had two functions it would controvert Muller s law of specificity of nerve conduction

Much however, may be said for the view expressed by Ingvar and Lenz that the pupillary fibres are non medullated and run in the periphery of the optic nerve

The pupillary fibres run in the optic nerve, for its division abolishes the direct but not the consensual light reflex *The pupillary fibres partially cross in the chiasma as do the visual, a portion going over to the opposite side, while the remainder pass on in the optic tract of the same side* We know that the pupillary fibres cross in the chiasma, because division of one optic tract abolishes neither the direct nor the consensual pupil reactions Experimental division of the chiasma abolishes neither the direct nor the consensual light reflex *Hence there must be a posterior crossing as well*

[1] See Behr *Die Lehre von den Pupillenbewegungen* 19?4

The pupillary fibres do not pass from the chiasma to the floor of the third ventricle, for experimental separation of the chiasma (Trendelenberg and Bumke, 1911) from this structure has no effect on the light reflex. *The pupillary fibres run in the optic tract*, division of which causes Wernicke's hemiopic pupil reaction.[1]

They leave the visual fibres at the posterior part of the tract, do not form a cell station at the external geniculate body, but run superficially in the anterior brachium conjunctivum to the outer side of the superior corpus quadrigeminum. Division of

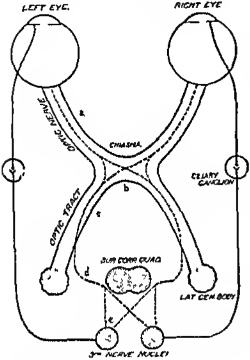

FIG 180—SCHEME OF THE PUPILLARY PATH (INTERRUPTED LINES)

Section at (*a*), i e of the left optic nerve, causes blindness of the left eye, abolition of the direct reaction to light of the left eye with retention of the consensual, and abolition of the consensual reaction of the right eye with retention of the direct

At (*b*), i e of the chiasma, causes bitemporal hemianopia, abolishes neither the direct nor the consensual pupil reaction

At (*c*) i e of left optic tract, causes contralateral (i e right) homonymous hemianopia, Wernicke's hemiopic pupil reaction

At (*d*) i e of the superior brachium on *both* sides, causes Argyll Robertson pupils

At (*e*), i e both afferent fibres coming to left nucleus, unilateral (left) Argyll Robertson pupil

At (*e*), on both sides causes bilateral Argyll Robertson pupils

There ought to be a cell station before the fibres reach the third nerve nuclei

both anterior brachia conjunctiva abolishes the pupil reactions to light on both sides (Karplus and Kreidl, 1913).

It is probable that the fibres which enter the superior corpus quadrigeminum have nothing to do with the light reflex, for as Levinsohn has shown, destruction of this body down to the iter has no effect on the light reflex

The main mass of pupillary fibres passes into the mid-brain to the outer side of the superior colliculus, partially crosses to the opposite side (possibly in the posterior commissure), and thus reaches the sphincter centre of the same and opposite side viâ the posterior longitudinal bundle.

In the intracerebral course there are one or more cell stations.

The Sphincter Centre is certainly in the anterior part of the 3rd nerve nucleus,

[1] See experiments by Karplus and Kreidl, 1913. Case of Marie and Chatelin, *Revue Neurologique*, 1915.

but it is not decided whether it lies in the small celled median nucleus of Perlia or in the small celled paired nucleus of Edinger Westphal.

To Sum Up.

The probable course of the afferent pupillary fibres is as follows (Fig. 180).

They start in the rods and cones—pass through the retina to reach the optic nerve, partially cross in the chiasma like the visual fibres, accompany the visual fibres in the tract to its posterior third, where they leave the tract as a separate bundle of fibres to enter the superior brachium conjunctivum, pass into the mid brain lateral to the superior colliculus, partially cross to reach the anterior part of the 3rd nerve nucleus (? Perlia, ? Edinger Westphal) of the same and opposite side via the medial longitudinal bundle.

We see therefore that there is a double crossing—namely, in the chiasma and in the mid brain.

The Efferent Tract.—*From the sphincter nucleus* the fibres pass *into the 3rd* nerve (where they probably occupy a central position)[1] then along its branch to the inferior oblique to reach the ciliary ganglion via its short root. Here they make a cell station. Then via the *medullated* short ciliary nerves they pierce the globe round the optic nerve, occupy a position between the choroid and sclera and so reach the sphincter pupillae.

The Pupillo-dilator Fibres.—The dilator centre (centrum cilio spinale of Budge) lies in the lateral column of the spinal cord at the junction of its dorsal and cervical regions. The dilator fibres leave the cord via the white rami communicantes of the 7th and 8th cervical and 1st and 2nd dorsal nerves. They pass up the cervical sympathetic cord to reach the superior cervical ganglion, where they form a cell station. From here the *post ganglionic* fibres run upwards with the sympathetic plexus around the internal carotid artery, which they leave to join the Gasserian ganglion. They pass into the orbit via the naso ciliary nerve and enter the eye via the long ciliary nerves and so reach the dilatator muscle.

A Higher Centre for the Dilator Path.—Although dilatation of the pupil results almost invariably from stimulation of the cerebral cortex, there is no cortical dilator centre. Parsons (1904) provisionally placed it in the mesen*cephalon near the third nucleus, but Karplus and Kreidl (1909) showed that it* was higher than this in the hypothalamic region.

With regard to the homologies between the sphincter and dilator systems the centrum cilio spinale of Budge corresponds to the sphincter centre in the mid brain, and the ciliary ganglion to the superior cervical ganglion.

PRACTICAL CONSIDERATIONS

1. The results on the pupillary reactions of division of the optic nerve, the optic chiasma, the optic tract, and the visual pathways behind the point of separation of the pupillary fibres have been discussed on p. 266.

[1] They probably lie in the middle of the cross section of the 3rd nerve, for as F[illegible] (190[illegible]) pointed out, in involvement of the nerve at the base of the skull the internal eye muscles are often spared.

2 Division of both brachia conjunctiva results in loss of the light reflex with retention of the reaction to convergence (Argyll Robertson pupil)

3 For the relation of the superior corpus quadrigeminum to the light reflex see p 274

4 Division of all the pupillary fibres in the mid brain before they reach the sphincter centre results in bilateral loss of light reflex with retention of the reaction to convergence (Argyll Robertson pupils)

5 If the direct and crossed fibres going to one sphincter centre only are divided a unilateral Argyll Robertson results The pupil does not react directly or consensually The reason for this is easily seen from the diagram, for the sphincter centre of the affected side cannot be reached from either eye The pupil on the sound side reacts directly and consensually

6 Total pupillary paralysis, that is, failure to react to light and convergence, may be due to (*a*) a supra (extra)nuclear lesion, (*b*) a nuclear lesion, (*c*) a lesion of the 3rd nerve, (*d*) a lesion of the ciliary ganglion, (*e*) a lesion of the short ciliary nerves It is probable that the fixed pupil in acute glaucoma is due to pressure on the short ciliary nerves as they lie between choroid and sclera The mydriatics (atropin, etc) act on the post ganglionic fibres of the para sympathetic, in this case the third fibres in the short ciliary nerves, (*f*) a lesion of the ciliary and sphincter muscles, (*g*) one ought to add here that loss of reaction to light and convergence may be due to mechanical causes—most commonly posterior synechiæ It should be noted that (apart from (*g*)) the larger the pupil the more complete the paralysis

7 *The Anatomy of the Argyll Robertson Pupil*—There are three main possibilities for the site of the lesion[1]

(*a*) That it is on the afferent side of the reflex arc just before the pupillary fibres reach the sphincter centre This is probably the most generally accepted view The difficulty about accepting this, and indeed all the other theories, is that it is based on practically no pathological evidence

(*b*) That it is on the afferent side the lesion being in the superior brachium conjunctivum Lenz and Ingvar believe that the pupillary fibres run superficially in the optic nerve and superior brachium They hold that the spirochætal (or other) toxin is in the cerebro spinal fluid, and will therefore affect the fibres nearest the subarachnoid space, i e pupillary fibres It will be remembered that Karplus and Kreidl produced the Argyll Robertson pupil by dividing the superior brachia

(*c*) That it is on the *efferent* side in the ciliary ganglion (Marina) While the pupillary fibres are certainly more vulnerable than those which have to do with convergence, it is difficult to see how, if the lesion were in so small a body as the

[1] In trying to fix a site for the lesion it is very important to remember that in the unilateral Argyll Robertson pupil the pupil on the affected side does *not* react to light directly or consensually, while the pupil on the sound side reacts to light both ways

ciliary ganglion, the Argyll Robertson pupil may be present for years and the reaction to convergence not be diminished but actually increased

There is very little to be said for Reichardt's view that the lesion is in the spinal cord

Practical Considerations

Division of the cervical sympathetic results in Horner's syndrome or Horner's triad ptosis, small pupil, and enophthalmos

The affected pupil does not dilate in the dark or after the instillation of cocaine or after pinching the neck (cilio spinal reflex) In bright light both pupils contract and their inequality disappears

The affected side of the face does not flush or sweat, and the ear feels colder than on the normal side *The area of absence of sweating includes* the whole of the upper limb (Purves Stewart, Sherren[1])

According to Levinsohn the ocular symptoms are more pronounced if the superior cervical ganglion is destroyed than if the cervical sympathetic cord forming the pre ganglionic fibres is cut

Injury to the cervical sympathetic may result from wounds, accidental or operative, and involvement in growths, etc The pupillary fibres may also be affected in the lower arm type of brachial birth palsy (Klumke's paralysis), and in injuries to the spinal cord

Stimulation of the cervical sympathetic results in exophthalmus, widening of the palpebral fissure, dilatation of the pupil, and often flushing and sweating It results from pressure by aneurisms, tumours, apical tuberculosis, etc

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[1] See Sherren in Choyce's *Surgery*

CHAPTER VIII

THE VESSELS

The Ophthalmic Artery

The ophthalmic artery arises from the medial side of the convexity of the fifth bend of the internal carotid just after this vessel has left the cavernous sinus by piercing the dura forming its roof. At its origin (Figs. 143, 144 and 145) the ophthalmic artery is medial to the anterior clinoid process and deep to the optic nerve. It runs directly forwards for a few millimetres under the *inner* side of the nerve, then bends outwards. Usually the origin of the artery lies under the middle of the nerve, but since its course here is antero-posterior and that of the nerve outwards as well as forwards, it may appear at the *inner* border of the nerve before eventually passing laterally (Figs. 139, 175).[1] The nearer the origin of the artery is to the optic foramen, the nearer the inner side of the nerve is it placed, and vice versa.

It passes through the optic canal in the dural sheath of the nerve, at first lying under it, then passing to its lateral side it pierces the sheath near its entrance into the orbit.

In the posterior part of the orbit it lies in the cone of muscles with the ciliary ganglion and the lateral rectus to its outer side and the optic nerve medial (Figs. 145, 146).

The artery ascends, passes over[2] the nerve and deep to the superior rectus to reach the medial wall of the orbit in company with its satellite naso-ciliary nerve (Fig. 145). It passes forwards between the medial rectus and superior oblique towards the internal angular process of the frontal, behind which it ends by dividing into nasal and frontal branches.

The ophthalmic artery and its branches are markedly tortuous.

Branches

1. The central artery of the retina (arteria centralis retinæ).
2. Posterior ciliary arteries.
3. The lacrimal artery.
4. Recurrent branches.
5. Muscular branches.
6. Supraorbital.

[1] Fawcett, *Journ. of Anat. and Phys.*, xxx, N.S. x, 1896, p. 49.
[2] See Variations, p. 291.

7 Posterior ethmoidal
8 Anterior ethmoidal
9 Superior and inferior medial palpebral
10 Nasal } terminal
11 Frontal }

1 **The Central Artery**—Its terminal branches have no anastomosis except a slight one with the circle of Zinn or Haller around the entrance of the nerve into the eye (see also p 99)

2 **The Posterior Ciliary Arteries** come off as two trunks while the ophthalmic artery is still below the optic nerve These divide into some 10 to 20 branches which running forwards surround the nerve and pierce the eyeball close to it The majority called the *short ciliary arteries* enter the choroid coat of the eye Two branches—*the long posterior ciliaries*—however pierce the sclera to the inner and outer sides of the nerve respectively (Fig 145) They run forwards between the sclera and choroid to supply the ciliary body and then anastomosing with the *anterior ciliary* arteries to form the *circulus arteriosus iridis major* (see p 62) supply the iris

3 **The Lacrimal Artery** arises from the ophthalmic to the outer side of the optic nerve It runs forwards at the upper border of the lateral rectus muscle in company with the lacrimal nerve (*q v*) to the lacrimal gland which it supplies Having passed through or to the outer side of the gland it supplies the conjunctiva and eyelids (Figs 144 145)

Branches—(*a*) The *recurrent meningeal* branch passes backwards through the sphenoidal fissure or through a small foramen in the great wing of the sphenoid to anastomose with the middle meningeal artery a branch of the internal maxillary which in turn comes off the external carotid This anastomosis is therefore one between the internal and external carotids i e between the primitive dorsal and ventral aortae At times it may be quite large and replace the ophthalmic in part

(*b*) *The temporal and zygomatic* (*malar*) *branches* accompany the corresponding *branches of the second division of the 5th nerve and anastomose with the* anterior deep temporal and transverse facial arteries respectively

(*c*) *The lateral palpebral* branches form arcades in the lids by anastomosing with the corresponding *medial palpebral* branches of the ophthalmic artery

4 **Small Recurrent Branches** pass back through the superior orbital (sphenoidal) fissure to join similar branches from the internal carotid Others run back in the dural sheath of the optic nerve

5 **The Muscular Branches** are usually given off as two main branches *lateral* and *medial* with a varying number of smaller twigs These latter come from the main artery and also from the lacrimal and supraorbital The lateral branch supplies the lateral and superior recti the levator and superior oblique The

medial branch is the larger of the two and supplies the inferior and medial recti and the inferior oblique (See the anterior ciliaries, p 60)

6 **The Supraorbital Artery** (Figs 141 to 145) comes off where the ophthalmic lies above the optic nerve It lies at first medial to the superior rectus and levator and then above the latter muscle and under the roof of the orbit It meets the nerve of the same name at the junction of the posterior and middle thirds of the orbit, and then accompanies it through the supraorbital notch or foramen and with it crosses the areolar tissue deep to the frontalis (the dangerous area) and so reaches the scalp where it anastomoses with the superficial temporal and frontal arteries It supplies the upper eyelid the scalp and also sends twigs to the levator, the periorbita and the diploe of the frontal bone

7 **The Posterior Ethmoidal Artery** (Fig 140) is a small vessel which enters the posterior ethmoidal canal in company with the posterior ethmoidal nerve (nerve of Luschka) when this is present It supplies the mucous membrane of the posterior ethmoidal air-cells and upper part of the nose

8 **The Anterior Ethmoidal Artery** (Figs 144 145 146) is larger than the preceding It comes off where the ophthalmic lies between the superior oblique and internal rectus It accompanies the nasal nerve through the anterior ethmoidal canal to appear in the anterior cranial fossa It enters the nose by a slit in the anterior part of the cribriform plate occupies the groove on the deep surface of the nasal bone and eventually appears on the face between the lateral nasal cartilage and the nasal bone

It gives the *anterior meningeal branch* to the dura mater of the anterior fossa and it also supplies the mucous membrane of the front part of the nasal cavity, the anterior ethmoidal air cells and the skin of the nose

9 **The Superior and Inferior Medial Palpebral Branches** come off near the front of the orbit They pass above and below the medial tarsal ligament to reach the upper and lower lids respectively (Fig 105) Here they lie in a plane between the orbicularis and the tarsal plate where they anastomose with the corresponding branches of the lacrimal to form the arterial arches or arcades of the lids (see p 133 and fig 106)

The medial palpebral arteries also send twigs to the conjunctiva the caruncle, and lacrimal sac

10 **The Nasal Branch** pierces the septum orbitale above the medial tarsal ligament to supply the skin of the root of the nose and the lacrimal sac It anastomoses with the angular and nasal branches of the facial (external maxillary) artery

11 **The Frontal Artery** (Figs 105 141) pierces the septum orbitale with the supratrochlear nerve which it accompanies It passes upwards, round the inner end of the supraorbital margin about ½ in (1 25 cm) from the mid line and supplies the skin muscles and periosteum of the medial part of the forehead It anastomoses with the supraorbital and with its fellow of the opposite side

VARIATIONS IN THE OPHTHALMIC ARTERY[1]

1 The ophthalmic artery in 15 per cent of cases crosses beneath instead of over the optic nerve

2 It may enter the orbit through the sphenoidal fissure

3 *The lacrimal often, and the ophthalmic rarely, may arise from the middle meningeal*—by an enlargement of the recurrent lacrimal artery which joins the lacrimal to the middle meningeal (that is, marks a union between primitive ventral and dorsal aortæ)

4 The lacrimal may be reinforced by the anterior deep temporal

5 The branches of the ophthalmic artery show great variation. The supraorbital and *posterior ethmoidal are both inconsistent and there are often accessory ciliary trunks* The nasal branch may replace the facial in part

THE CEREBRAL ARTERIES (Figs 174 and 175)

The Anterior Cerebral Artery arises from the internal carotid close to the Sylvian fissure crosses above the optic nerve, and approaching its fellow of the opposite side is joined to it by *the anterior communicating* vessel which is, *as a rule about 4 mm long It then curls* round the front or *genu* of the corpus callosum on the upper aspect of which it runs to the splenium, where it anastomoses with the posterior cerebral

It supplies the front of the caudate nucleus by branches which enter the anterior perforated substance, the corpus callosum, the medial aspect of the hemisphere as far back as the parieto-occipital fissure, a small strip on the upper part of the lateral surface, and the medial portion of the under surface of the frontal lobe

Blocking of this vessel may give rise to no symptoms but hebetude and dullness of intellect may result (Osler)

The Middle Cerebral Artery is the largest branch of the internal carotid of which it appears to be the direct continuation It runs outwards into the Sylvian fissure, and breaks up into branches on the island of Reil which supply the lateral aspect of the hemisphere, except for a strip near its upper border (anterior cerebral) and a strip along the lower border *(posterior cerebral)*

It also sends the medial and lateral striate arteries through the anterior perforated substance

The *medial striate arteries* pass through the inner part of the lentiform nucleus, which they supply and also send branches to the caudate nucleus

The *lateral striate arteries* pass between the lentiform nucleus and the external capsule The largest of these was called by Charcot the ' artery of cerebral hæmorrhage

The Posterior Communicating Artery runs backwards above the 3rd nerve, to join the posterior cerebral It sends twigs to the optic tract and branches through the posterior perforated substance to the optic thalamus

The Anterior Choroidal Artery passes backwards with the optic tract which it supplies (Fig 174), and then through the choroidal fissure to join the choroid plexus of the inferior horn of the lateral ventricle It also sends twigs to the external geniculate body (see p 264)

Blocking of the middle cerebral—' the artery most commonly involved—results in permanent hemiplegia from softening of the internal capsule, if plugged before the central arteries are given

[1] See F Mayer *Morph Jahrb*, xii 1886

off Blocking of the branches beyond this point may be followed by hemiplegia which is more likely to be transient, involves chiefly the arm and face and if the lesion be on the left side associated with aphasia There may be plugging of the individual branches passing to the inferior frontal gyrus (producing typical motor aphasia if the disease be on the left side), to the anterior and posterior central gyri (usually causing total hemiplegia) to the supra marginal and angular gyri (giving rise—if the thrombosis be on the left side, probably without exception—to the so called visual aphasia and usually also to right sided hemianopsia), or to the temporal gyri (in which event with left sided thrombosis word-deafness results) (Osler)

The Circle of Willis (Figs 130, 175 177) is an anastomosis between the two internal carotids and the basilar *It is the most important reason why ligature of one or other common or internal carotid does not always produce cerebral softening* It lies in the subarachnoid space, and surrounds the structures in the interpeduncular fossa

It is formed as follows behind the basilar divides into the two posterior cerebrals these are united to the internal carotids by the posterior communicatings From the internal carotid, running forwards and inwards are the anterior cerebrals, and uniting these is the anterior communicating.

The Basilar Artery is formed by the union of the two vertebrals at the lower border of the pons It runs upwards in the median groove of the pons on the base of the skull, and at its upper border bifurcates into the two posterior cerebral arteries

Blocking of the basilar artery may produce bilateral paralysis from involvement of both motor paths Bulbar symptoms may be present rigidity and spasm may occur The temperature may rise rapidly The symptoms in fact, are those of apoplexy of the pons" (Osler)

Branches (Bilateral)

Pontine —Several on each side to the pons

Internal Auditory runs with the 7th, 8th and pars intermedia into the internal auditory meatus, and is distributed to the internal ear

The Antero-inferior Cerebellar usually crosses the 6th nerve on its ventral aspect (Figs 132, 175), but it may pass between it and the pons, or through its fibres The author has seen the nerve pressed into the substance of the pons by an arterio-sclerotic vessel The artery supplies the anterior and inferior surfaces of the cerebellum

The Superior Cerebellar comes off close behind the posterior cerebral It winds round the cerebral peduncle, having the 3rd and 4th nerves between it and the posterior cerebral It supplies the upper surface of the cerebellum

The Posterior Cerebral Artery (Figs 153 174) runs round the cerebral peduncle parallel to the superior cerebellar and below the optic tract The 3rd and 4th nerves pass between the two arteries The posterior cerebral proceeds backwards above the free margin of the tentorium cerebelli to the calcarine fissure, where it divides into branches which run in the parieto occipital and calcarine fissures respectively

It supplies (*a*) the medial and posterior part of the lateral surface of the occipital lobe, (*b*) the whole of the tentorial surface of the hemisphere, except the anterior part of temporal lobe, and also central branches to the thalamus,

internal capsule, red nucleus, geniculate bodies, velum interpositum and choroid plexus of the lateral ventricle

A block of the right posterior cerebral artery causes

(a) *Destruction of the visual fibres from the right side of each retina, that is, from the left fields—and hence produces a left homonymous hemianopia*

(b) *Sensory aphasia*

(c) *Sometimes hemianæsthesia from involvement of the posterior part of the internal capsule*

Very often the posterior cerebral of one side thromboses with the middle cerebral of the other, and produces the most pronounced cases of apraxia (Osler)

The Veins

The orbit is drained by the superior and inferior ophthalmic veins They and their tributaries are curious in having no valves, being markedly tortuous and having many plexiform anastomoses They communicate, moreover, with the veins of the face, with the pterygoid plexus, with the veins of the nose, and with the cavernous sinus

The Superior Ophthalmic Vein

The Superior Ophthalmic Vein is formed near the root of the nose by a communication from the angular vein soon after it has been joined by the supra orbital

It passes into the orbit above the internal tarsal ligament, and then accompanies the ophthalmic artery across the optic nerve and under the superior rectus to the sphenoidal fissure, by which having, as a rule, been joined by the inferior ophthalmic vein, it leaves the orbit to enter the fore part of the cavernous sinus

Its position in the sphenoidal fissure is usually above the cone of muscles, but it may pass between the two heads of the lateral rectus, or occupy the lowest compartment of the fissure

Tributaries

(a) The inferior ophthalmic vein usually (*vide infra*)
(b) Anterior ethmoidal
(c) Posterior ethmoidal
(d) Muscular
(e) Lacrimal
(f) Central vein of retina
(b)–(f): correspond to the arteries of the same name
(g) Anterior ciliary
(h) (Two of the) venæ vorticosæ or posterior ciliary veins

The Central Vein of the Retina leaves the optic nerve close to the central artery, but usually nearer the bulb (**Vossius**) As a rule it opens directly into

the cavernous sinus, but may end in the superior ophthalmic vein to which, as Sesemann showed, it always gives a well marked anastomotic branch This is of some practical importance

Graefe thought that papillœdema was due to venous stasis produced by pressure on the cavernous sinus and then back along the vena centralis Sesemann's observation negatived this theory

The Anterior Ciliary Veins accompany the arteries of the same name They

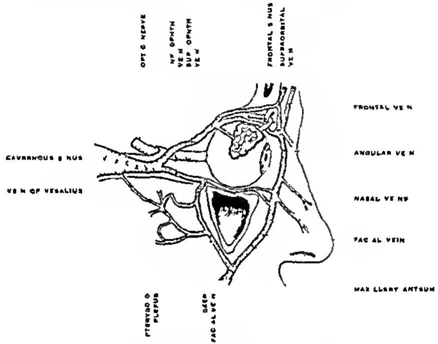

FIG 181 —SCHEME OF THE VEINS OF THE ORBIT
(*Slightly after Allen Thomson*)

pierce the sclera near the cornea, and then having received some branches from the conjunctiva join the muscular veins (see also p 61)

The Inferior Ophthalmic Vein commences as a plexus near the front of the floor of the orbit It runs backwards on the inferior rectus to enter the cavernous sinus either after having joined the superior ophthalmic vein or separately

In the latter case it passes through the sphenoidal fissure either between the two heads of the lateral rectus or occupies the lowest compartment In the latter position it is in relation with Muller's muscle, which may, it is said, compress the vein and produce exophthalmos [1]

The inferior ophthalmic vein communicates with the pterygoid plexus through the inferior orbital (spheno maxillary) fissure, with the anterior facial vein over

[1] Very improbable

the inferior orbital margin and with the superior ophthalmic vein It also gets tributaries from the lower and lateral ocular muscles, the conjunctiva and lacrimal sac, and receives the two inferior vorticose veins

The Angular Vein

The angular vein is situated at the junction of the veins of the forehead, orbit, and face It is formed by the union of the supraorbital and frontal veins, and runs down at the side of the nose lateral to the angular artery, across the nasal edge of the medial palpebral ligament some 8 mm from the inner canthus (Fig 110) It is subcutaneous, and visible (as a dark blue ridge) through the skin here, and above and below this point till it pierces the orbicularis The angular vein (or one of its palpebral branches) is one of the bugbears in approaching the lacrimal sac from the front It communicates freely with the beginning of the *superior ophthalmic vein*, and is continuous below with the *facial vein*

Tributaries—(*a*) **The Supraorbital Vein** runs transversely along the orbital margin deep to the orbicularis, which it pierces under the inner end of the eyebrow to join the frontal and form the angular vein It communicates with the superior ophthalmic vein through the supraorbital notch, at which point it receives a vein from the frontal sinus and the diploë

(*b*) **The Frontal Vein** runs down the forehead, accompanying the supraorbital artery

(*c*) **The Superior and Inferior Superficial Palpebral Veins** *One of the upper veins not infrequently crosses the medial palpebral ligament between the angular vein and the medial canthus, where it, too, can be made out through the skin*

(*d*) **Superficial Nasal Branches**—from the side of the nose

The Facial Vein runs obliquely downwards and backwards across the face *It is lateral to and more superficial than its accompanying artery It crosses the mandible, and joins the posterior facial vein to form the common facial vein,* which opens into the internal jugular

The (anterior) facial vein communicates with the pterygoid plexus of veins (Fig 181), and thus establishes a second communication with the cavernous sinus (*q v*), the first being via the angular and superior ophthalmic veins

The flow of blood from the frontal region is largely into the orbit Hence the danger of septic spots on the forehead and face, which may result in cavernous sinus thrombosis

The Cavernous Sinuses

Like the other intracranial venous sinuses, the cavernous sinuses are venous channels formed by the splitting of the dura mater (Fig 182)

They extend on each side of the pituitary body and body of the sphenoid

from the inner end of the superior orbital (sphenoidal) fissure to the apex of the petrous part of the temporal bone

They are traversed by numerous fibrous trabeculæ which give them on section the appearance of cavernous tissue and from this fact they derive their name

In each sinus is found the internal carotid artery and lateral to it the 6th nerve Both these structures receive an investment from the thin lining membrane of the sinus

The internal carotid artery enters the sinus by passing upwards from the termination of the carotid canal at the medial end of the foramen lacerum between the lingula and the petrosal process of the sphenoid (Figs 10 132) It then runs forwards in its groove on the body of the sphenoid (q v) to the medial

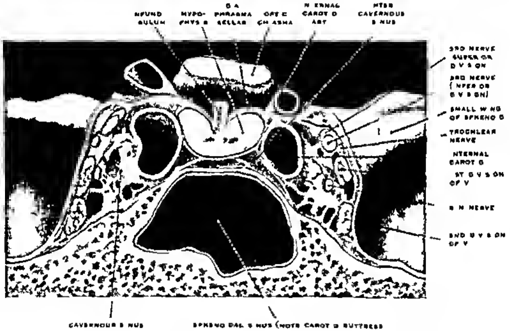

Fig 18 —The Cavernous Sinuses
(From Professor Elliot Smith's Textbook of Anatomy Drawn from a Dissection in the Moorfields Path lo l Museum)

side of the anterior clinoid process where it turns upwards and pierces the roof of the sinus between the optic and oculo motor nerves (Fig 130)

While in the sinus it is surrounded by filaments of the sympathetic and a venous plexus

It is this close relation of the artery to the sinus which explains how arterio venous aneurisms may arise in fracture of the base of the skull

In the *lateral wall* of the sinus from above down are the 3rd, 4th and first and second divisions of the 5th cranial nerves They are passing forwards to the

superior orbital fissure and foramen rotundum respectively At the anterior end of the sinus the 4th nerve crosses to lie above the 3rd (see p 200)

To the outer side of these again, and in contact with the lateral wall of the sinus, are the Gasserian ganglion (Fig 139) and the temporal lobe of the brain

Tributaries —*In front*, the ophthalmic veins and the spheno parietal sinus, which lies along the lesser wing of the sphenoid

On the outer side, the Sylvian (or middle cerebral) vein, and emissary veins which may pass through the foramen ovale and foramen lacerum Also communications with the middle meningeal vein

Below, the emissary vein of Vesalius

Behind, the superior and inferior petrosal sinuses

Medially, the circular sinus

Most of these tributaries are of great practical importance

The Ophthalmic Veins communicate with the angular vein on the face *This is the reason why a small septic spot on the nose, for instance, may produce thrombosis of the cavernous sinus*

The Emissary Vein that passes through the foramen of Vesalius communicates with the pterygoid plexus, so also do the veins that pass through the foramen ovale and foramen lacerum

Moreover, there are indirect communications with the pterygoid plexus viâ the deep facial vein which unite it to the anterior facial vein, the continuation of the angular, and viâ the branch which the inferior ophthalmic vein sends to the plexus, through the *inferior orbital* (spheno maxillary fissure) (Fig 181)

The pterygoid plexus of veins corresponds to the second and third parts of the internal maxillary artery and covers both surfaces of the external pterygoid muscle and also the inner surface of the internal pterygoid

Thus we have the anatomical explanation of how a thrombosis of the cavernous sinus may spread to the pterygoid plexus and produce an abscess so often found post mortem in this condition in the tonsillar region (*Percy Flemming*)

The Superior Petrosal Sinus runs in the upper border of the petrous temporal in the attached margin of the tentorium cerebelli It crosses above the 5th and 6th nerves and unites the cavernous sinus with the transverse It is usually small

The Inferior Petrosal Sinus is placed in the groove between the petrous temporal and basi occipital (Fig 85) It is crossed obliquely from within outwards by the 6th nerve and receives veins from the internal ear It unites the cavernous sinus with the beginning of the internal jugular vein below the base of the skull

The petrosal sinuses *explain how thrombosis in the cavernous sinus may spread to the lateral, and finally also produce a swelling behind the ear through the mastoid emissary vein* This passes through a foramen in the mastoid part of the temporal bone, and unites the sigmoid sinus with the veins of the scalp The fact

that the auditory veins open into the inferior petrosal sinus marks the route *by which infection of the labyrinth may produce cavernous sinus thrombosis*

The Circular Sinus is usually described as consisting of anterior and posterior intercavernous sinuses which connect the two cavernous sinuses and surround the sella turcica of the pituitary body Very often however they are in the form of a *plexus* of veins The circular sinus explains *how the thrombosis of the cavernous sinus in the majority of cases becomes bilateral*

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CHAPTER IX

THE DEVELOPMENT OF THE EYE

THE central nervous system is derived from a thickening in the ectoderm called the *neural* or *medullary plate*. This becomes converted into a groove and then into a canal which is separated from the surface ectoderm and designated the neural ectoderm. The anterior end of the neural ectoderm expands to form the three primary brain vesicles.

The eye is partly mesodermal, partly ectodermal in origin. The ectodermal portion is derived from that region of medullary plate which goes to form the fore brain and also from the ectoderm of the surface of the body.

There are three stages in the early development of the *retina* and *optic nerve*:

1. The optic groove.
2. The primary optic vesicle.
3. The secondary optic vesicle or optic cup.

The optic grooves appear on either side of the mid line in the anterior end of the medullary plate at a time when the medullary plate at this end of the embryo has been converted into a groove, but before its closure to form a canal. The primordium of the retina therefore appears very early; in fact it is already seen in a 2.2 mm embryo.

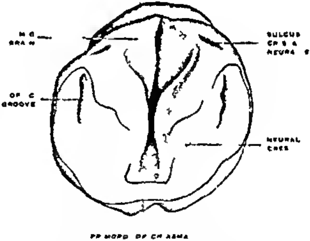


FIG 183.—MODEL OF ANTERIOR END OF A HUMAN EMBRYO OF TWELVE SOMITES × 70.
(*Fischel after Bartelmez-Evans.*)

The areas of opposite sides are joined by a narrow zone which later becomes the chiasma (Figs. 183, 183A).

On the closure of the medullary canal the optic grooves deepen and appear as hollow symmetrical hemispherical outgrowths at the side of what is now the fore brain vesicle. The growth is affected by cell division, the mitoses taking place almost entirely on the inner aspect next the cavity of the primary optic vesicle.

The cavity of the hollow outgrowth or primary optic vesicle will naturally communicate with that of the fore brain vesicle (Fig. 184). As development

proceeds, the vesicle becomes separated from the fore brain by a constriction, its pedicle or stalk, which is best marked dorsally (Fig 184) The primary optic vesicle grows mainly laterally with a slight inclination anteriorly and upwards and in the 4 mm embryo it has reached the surface ectoderm

Opposite the distal end of the primary optic vesicle but separated from this

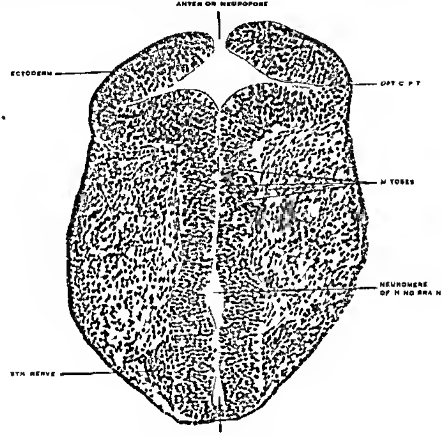


Fig 183a —Horizontal Section through the Fore and Hind brains of a Human Embryo of Eighteen Somites × 133

(Fisch l)

by a reticulum of protoplasmic[1] fibrils there is a thickening of the surface ectoderm which represents the first stage of the development of the lens (Fig 184)

With the conversion of this thickening first into a groove and then into the lens vesicle, the primary optic vesicle is first flattened, and then as it were "invaginated" from its distal aspect and below

[1] I e the embryonic supporting tissue of von Szily Similar tissue will be seen to exist later between the lens and the inner layer of the optic cup and there form what is known as the primary vitreous

Thus the two layered secondary optic vesicle or optic cup is produced

In the mechanism of production of the secondary optic vesicle it used to be taught that the lens actually pushed in the distal wall of the primary optic vesicle, as one might push in the wall of a toy balloon with one's fist. Its formation is, however, due to the fact that the distal and lower portions of the vesicle stop growing, while the margins of these areas continue to develop. Thus the lips of the vesicle grow round the developing lens at the sides and above, but not below.

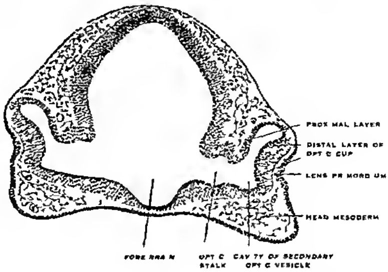


FIG 184 —TRANSVERSE SECTION THROUGH THE FORE BRAIN OF A 5 MM HUMAN EMBRYO

(From Seefelder, in the Kurzes Handbuch.)

Since the apex of the vesicle, which was originally convex, stops growing, and as it is in contact with the lens, it first appears flattened and then becomes concave. Thus the lumen of the vesicle is reduced to a slit.

Since growth also stops below, this area remains depressed, while its margins continue developing and thus is formed the **fœtal, ocular, or choroidal cleft**.

The function of the fœtal cleft or fissure, apart from allowing the entrance of mesoderm into the eye, is to provide the shortest route by which the nerve fibres from the ganglion cells can reach the optic stalk and brain. Otherwise, with the formation of the secondary optic vesicle, they would have to travel round the edge of the cup.

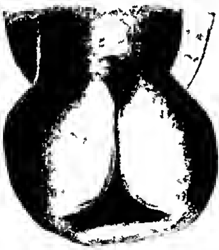


FIG 184A —PRIMORDIUM OF EYE OF 7 MM HUMAN EMBRYO FROM BELOW × 100

(From Seefelder in the Kurzes Handbuch d Ophth., 1930.)

[In early embryos (between 7 7 and 17 1 mm (Lindahl)), the rim of the

optic cup may present small *accessory notches* Their significance is doubtful Possibly they are made by vessels]

Hence it comes about that as the lens pit is converted into a little pouch or sac, the optic cup also deepens and surrounds it more and more Also the opening of the cup is gradually differentiated into a laterally directed rounded portion the primitive pupil, and a downwardly directed part, the choroidal cleft

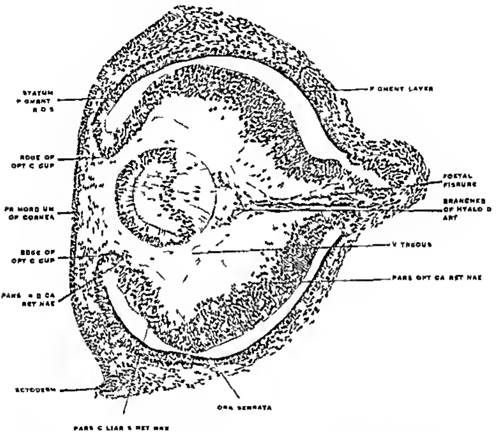


FIG 185 —SECTION THROUGH THE EYE AND FŒTAL FISSURE OF A 13 5 MM HUMAN EMBRYO × 157 (*From Fisch l*)

Note the eversion of the inner layer of the optic cup at the posterior end of the choroidal figure

(Fig 184A) The choroidal cleft at first only extends to the beginning of the optic stalk Through it the mesoderm which will eventually form the hyaloid system of vessels enters the optic cup

The optic cup or secondary optic vesicle is thus composed of two layers which are continuous with each other at the margin of the cup and at the fœtal fissure The inner layer is much thicker than the outer, and will form the nervous portion of the retina, while the outer layer gives rise to the pigment epithelium only

The cavity of the primary optic vesicle is potential only but pathologically can be reconstituted into a real cavity This happens in detachment of the retina when fluid collects between the pigment layer (which remains adherent to the choroid) and the rods and cones

Similarly in the separation of posterior synechiae the posterior of the two layers

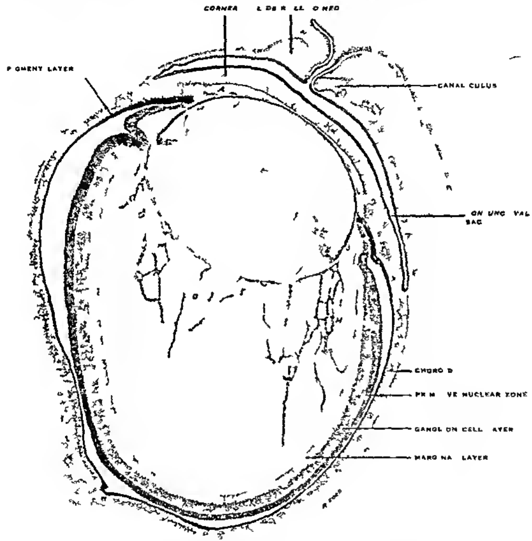


FIG 18[illegible] —VERTICAL SECTION OF THE EYE OF AN EMBRYO OF 2¼ MONTHS (38 MM)
A = anterior chamber (artefact) *H = hyaloid vessels*
(Author's preparation from a specimen kindly supplied by Dr A G G[illegible])

of the ectodermal part of the iris becomes separated from the anterior and remains adherent to the lens This separation re forms the anterior part of the cavity of the primary optic vesicle or ring sinus of von Szily which indeed may also take place as a senile change

The ocular cleft closes by its lateral walls growing towards each other and eventually fusing. This fusion begins at the centre at the fifth week and extends forwards and backwards.

Anteriorly a small notch remains before the fusion completes the primitive

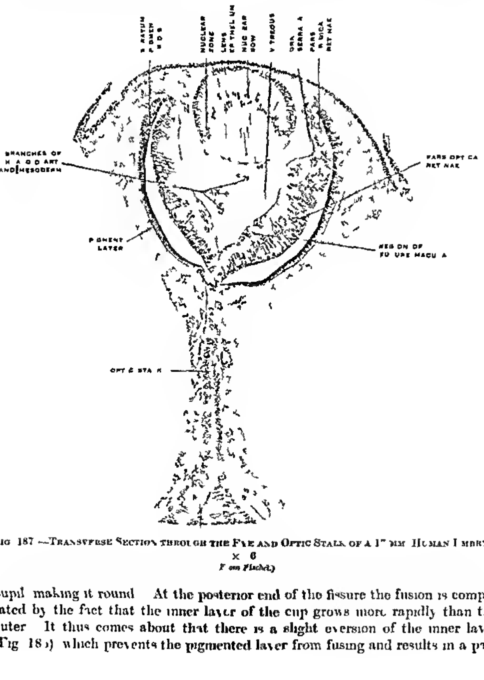


Fig. 187.—Transverse Section through the Eye and Optic Stalk of a 17 mm. Human Embryo. × 6. (From Fischel.)

pupil making it round. At the posterior end of the fissure the fusion is complicated by the fact that the inner layer of the cup grows more rapidly than the outer. It thus comes about that there is a slight eversion of the inner layer (Fig. 188) which prevents the pigmented layer from fusing and results in a pale

area below the disc In man,[1] however, this pale area soon becomes pigmented, and usually no trace is left of the fissure except at its extreme posterior end, which remains as the site of entry of the central vessels

Non closure of the cleft results in colobomata

With the closure of the cleft the portion of the mesoderm which has made its way into the eye through the cleft is cut off from the surrounding mesoderm, and gives rise to the hyaloid system of vessels

The Development of the Retina

The primordium of the nervous portion of the retina is the distal wall of the primary optic vesicle, and consists at first of a single layer of cylindrical epithelium The nuclei soon divide and become arranged in several layers The mitoses take place at the side next the future pigment layer so that the oldest cells get pushed towards and lie nearest the future vitreous (Fig 188)

As the retina rapidly increases in thickness it becomes divided into a **nuclear zone** and a zone containing at first no nuclei—the **marginal layer of His** (Figs 185 186) This is formed by anastomotic protoplasmic processes of the retinal cells and is the *primordium* of the supporting tissue of the retina—namely the neuroglia

At the time of the formation of the secondary optic vesicle the marginal layer is well developed as are also the internal and external limiting membranes The retina remains in this primitive condition until the closure of the optic cleft

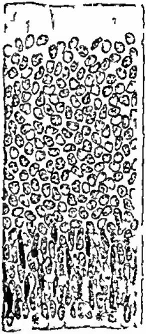


Fig 188—Section of the Retina (near the Posterior Pole) of a 31 mm Human Embryo

(From Seefelder in the Kurzes Handbuch.)

The Ganglion Cells and the Nerve Fibre Layer—The ganglion cells are formed from the innermost cells of the *nuclear zone* which invade the *marginal zone* at about the fifth week (in embryos of 11 3 to 13 mm) This latter takes place first in the region of the future macula

These young neuroblasts have a small round nucleus and practically no protoplasm Later the nuclei grow larger stain less deeply and are then easily distinguished from the deeper staining nuclear zone (Fig 188)

No sooner have the ganglion cells invaded the marginal zone than the nerve fibres grow out from them run parallel to the surface of the retina to find the shortest way to the optic stalk and thence to the brain

[1] *In birds it develops into the cauda (see p 336)*

The differentiation of the retina proceeds from the posterior portion of the eye anteriorly

With the formation of dendritic processes from the outer aspect of the ganglion cells a clear non nuclear zone is produced between these and the remaining cells and thus is formed the beginning of the inner molecular layer Later are added the branching processes of the inner horizontal and bipolar cells

The Nuclear Layers and Outer Molecular Layers —The separation of the two nuclear layers also takes place first in the central area and about the same time as

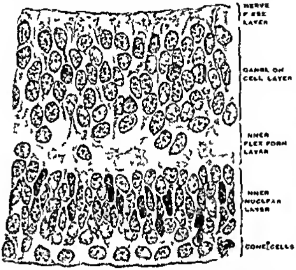


FIG 189 —MACULAR REGION OF A 6 MM HUMAN EMBRYO

(From Seefelder in the Kurze Handbuch)

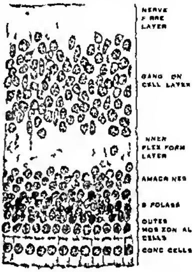


FIG 190 —THE MACULAR REGION IN A FOETUS OF FIVE MONTHS

(From Seefelder in the Kurze Handbuch.)

the formation of the inner molecular layer while from the primitive nuclear zone a single layer of the outermost cells separates to form the future cones and rods (Fig 189)

Between these cone cells and the remaining cells is a clear zone containing Muller s fibres only

The outer molecular (plexiform) layer is developed about the end of the fifth month at first by processes of the middle cell layer

In the inner nuclear layer Muller s fibres are first developed then the bipolar cells, then the inner horizontal cells (amacrines) and lastly the outer horizontal cells

Probably no new retinal cells are produced after the sixth month Thus the relative size of the pars optica of the retina to the whole bulb is much greater in the embryo, where it reaches to the cornea than in the adult where it ends at the equator

The Rods and Cones —The *rods and cones are* developed from a single row of cells which separate from the primitive nuclear zone The diplosomes which lie in the outer side of these primitive cells play an important part in their development

The young cone cells have a small round deeply staining nucleus and a fair amount of protoplasm which lies next the outer limiting membrane Later the protoplasm and the diplosomes break through this, and the cone cells become cylindrical and more like epithelial cells Threads pass outwards from the diplosomes which, becoming surrounded by a soft protoplasmic material, form the outer[1] portion of the cones The rods are developed in a similar way

The Area and Fovea Centralis —In the third month a marked thinning is seen in the retina of the postero lateral quadrant (Fig 186) All layers are affected *This, however, does not constitute the macula* The appearance of the macular area is shown by a thickening of the ganglion cell layer at about the fifth month (fœtus

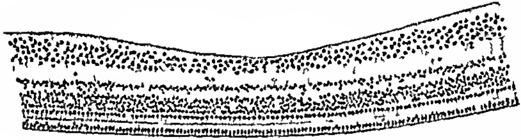


FIG 191 —THE FOVEA CENTRALIS OF A FŒTUS AT THE END OF THE SIXTH MONTH

(From Seefelder in the Kurzes Handbuch)

of 122 mm according to Seefelder) between the above area and the papilla

In the fifth month there is developed in the central area an additional fibre layer, namely the transitory layer of Chievitz, which only disappears after birth Its significance has not yet been decided It is formed through the inner horizontal cells (amacrines) separating from the remainder of the inner nuclear layer (Fig 191)

The development of the fovea commences at the end of the sixth month by a thinning of the ganglion cells, which move away to leave a central shallow depression This is deepened by a thinning of the outer layers except of course the outer nuclear layer, which remains as before one layer thick Up to the time of the formation of the fovea the development of the macula precedes the remainder of the retina, but after this it falls behind especially with regard to the neuro epithelium At birth the foveal cones are still very plump structures, and it is only when the child is several months old that it gets its definitive form, and only then can the central area show its superiority over the remainder of the

[1] Some hold that the cilia which line the primary optic vesicle help to form the outer portion of the rods and cones

retina Hence also the reason for the absence of central fixation at birth It is remarkable that the fovea centralis is as far away from the nerve head at its formation as in the adult

The thickening of the outer cell layer in the region of the fovea arises after birth and results from the fact as pointed out by Druault that as the limbs of the cones get thinner they are more crowded together and therefore also their nuclei

From the fourth to the eighth month of fœtal life as was first pointed out by von Ammon and confirmed by Treacher Collins and others the retina may be thrown into folds which however disappear completely

The Outer Retinal Layer (Pigment Epithelium)

With the invagination of the primary optic vesicle the two layers of the

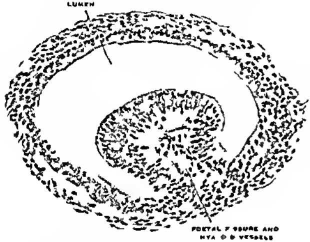


Fig 1? —Transverse Section of the Optic Stalk of a 8 mm Human Embryo Distal Portion

(From Fischel 19 9)

secondary optic vesicle which have at first the same epithelial structure start differentiating

The cells of the outer layer are at first high cylindrical occupy its whole thickness and have their nuclei arranged in two or three rows

Pigmentation of the cells starts in embryos of from 6 to 7 mm (about one month) The anterior portion is pigmented first and then the process passes backwards

By the time the embryo has reached 10 mm the whole of the outer layer is pigmented

As development proceeds the pigment cells become flatter probably because they have to line a larger area

[1] The pigment is formed in the cell itself Probably there is a colourless precursor of the melanin pigment of the nature of dioxyphenyl alanine (dopa) which is converted to melanin by a peroxidase ferment

[1] Moscher *Die Pigment Genese Arch mikrosk Anat* 97 (192)

The Optic Nerve

The optic nerve is developed from the optic *stalk* or *pedicle*, which is at first quite short. Its cavity communicates on the one hand with the fore brain vesicle, and on the other with the primary optic vesicle (Fig. 184).

After the formation of the secondary optic vesicle the fœtal cleft extends for some distance along the optic stalk. Both this and the cavity of the stalk are closed by the development of the nerve fibres which grow cranialwards from the ganglion cells.

The epithelial cells forming the walls of the stalk develop into the glial system of the nerve.

At the third month the glial cells become arranged in rows parallel to the long axis of the optic nerve and between these the nerve fibres run.

Glial tissue also develops round the hyaloid artery and around the periphery of the nerve. The glial tissue or glial mantle around the hyaloid artery at its entrance into the vitreous forms a protruding mass (glial cushion or Bergmeister's papilla[1]), which not only clothes the artery and some of its branches, but fills the physiological excavation of the optic nerve head as well.

With the regression of the hyaloid artery this glial mantle disappears also.

The fibrous (mesodermal) septa of the optic nerve are developed from the mesoderm of the vessels which invade the nerve at the middle of the third fœtal month and which have the form and position of the future septa. The mesodermal lamina cribrosa is only formed in the last fœtal months, and then has not the strength of the previously existing glial lamina (Seefelder).

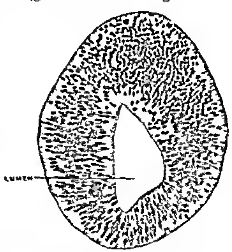


Fig. 193.—Transverse Section of the Optic Stalk of a 9 mm. Human Embryo. Proximal Portion.
(*From Fischel.*)

The nerve sheaths are derived from the head mesoderm and develop concurrently with the posterior part of the sclera. At the fifth month dura, arachnoid, and pia can be distinguished from each other.

Medullation of the nerve fibres takes place from the brain distally, and reaches

[1] **Bergmeister's Papilla.**—*As the optic nerve fibres pass from the ganglion cells to the optic stalk they have to traverse the remainder of the retina.* As they do this they cut off a cone-shaped mass of glial cells at the centre of the disc which is known as Bergmeister's primitive epithelial papilla. This becomes vascularised by the hyaloid artery and supplies this vessel and its branches with their sheaths (Seefelder 1910, von Szily 1921, 2). Later with the disappearance of the hyaloid system the papilla also atrophies, *the amount of atrophy determining the depth of the physiological cup.*

Remains of the papilla are always found in the glial sheaths of the vessels and the glial tissue which separates the optic cup from the vitreous (the central connective tissue meniscus of Kuhnt).

Fig. 184.—Transverse Section of the Ocular End of the Optic Nerve of a 19 mm. Human Embryo.

(From Seefelder in the Kuss Handbuch.)

the lamina cribrosa just before birth. The so-called congenital nerve fibres seen not infrequently near the disc are therefore not really congenital at all, since they are medullated after birth. At six weeks the optic fibres penetrate the under surface of the fore-brain; at about seven and a half weeks the chiasma has been formed by partial decussation of the fibres, and at nine and a half weeks the optic tract is plainly present.

The Development of the Lens

Stages:

(a) Lens plate.
(b) Lens pit.
(c) Lens pouch or sac.
(d) Lens vesicle.

At the 4.5 mm. stage the surface ectoderm opposite the distal part of the primary optic vesicle is thickened by the cells assuming a high[1] columnar form, and their nuclei, which show mitotic figures, are arranged in several layers. This thickening is called the lens plate (Fig. 184). A groove or pit appears in this. The pit deepens into a pouch which closes and forms a vesicle at about four and a half weeks. The lens vesicle moves away slightly from the surface ectoderm, being connected to it, however, by a protoplasmic reticulum, the embryonic supporting tissue of von Szily.

With the formation of the lens vesicle the primary optic vesicle is "invaginated" to form the optic cup or secondary optic vesicle.

At this stage the optic cup is almost completely filled by the lens.

The human lens vesicle contains some loose degenerate cells (see Fig. 235) which Schwalbe believes later go to form the thin layer of amorphous substance beneath the anterior epithelium.

Fig. 185.—To illustrate the Course of the Fibres in the Fœtal Crystalline Lens.

A = anterior pole.
P = posterior pole.

(After Allen Thomson, from Quain's Anatomy.)

[1] According to Rabl (Über den Bau und die Entwicklung der Linse, 1899) the cells forming the lens plate in mammals are high, very narrow and closely packed, but always arranged in a single layer like that of birds and reptiles. The appearance on section of several layers is given by the nuclei being situated at different levels in different cells.

The cells of the posterior part of the vesicle become columnar and eventually elongate to fill the lens vesicle. These primitive lens fibres run from the front to the back of the lens ; *later none do.*

The nuclei of the lens fibres pass anteriorly, and at the equator form a line convex forwards (the nuclear bow) (Fig. 186), which is continuous laterally with

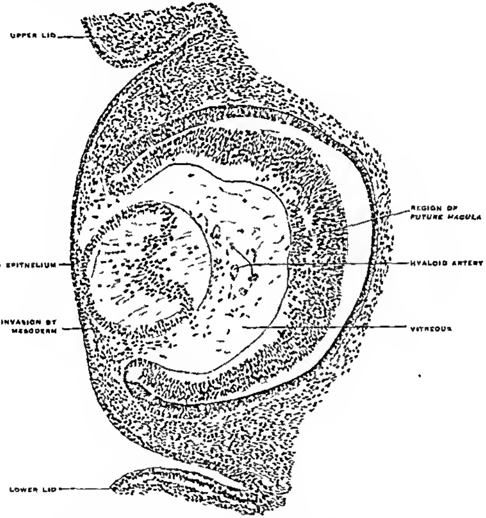


FIG. 196.—SECTION THROUGH THE EYE OF 17 MM. HUMAN EMBRYO. × 148. (*From Fischel*)

the equatorial nuclei of the cells of the anterior epithelium which will form all except the first fibres.

The new lens fibres formed from the equatorial cells are laid down concentrically round the filled-in lens vesicle, and thus the lens gets its laminated structure.

As pointed out above, none of these runs from the front to the back of the lens They start and finish in the lens sutures which are present at the beginning of the third month In the infantile lens these form an anterior upright Y and a posterior inverted ⅄ respectively (see Fig 116)

Each fibre starts in such a way that the nearer the axis of the lens it commences the farther away it ends (Fig 195) The fibres formed later, for instance the superficial ones of the adult lens, start and finish in the more complicated stellate figures, conforming however, to the above rule (see also p 110)

The Lens Capsule —At the 13 mm stage the lens epithelium secretes its hyaline capsule, which prevents it from taking any further part in the development of the vitreous

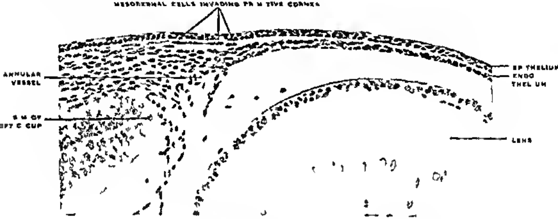


Fig 197 —Antero posterior Section of a 23 mm Human Embryo
(From Seefelder in the Kurz s Handbuch)

The Cornea

After the formation of the lens vesicle mesoderm cells grow into the protoplasmic[1] fibrillæ (the so called anterior vitreous) between the lens and the surface ectoderm They become arranged in a single row parallel to the surface and go to form Descemet's endothelium

Into the space between Descemet s endothelium and the surface ectoderm there grow more mesodermal cells from the region of the edge of the optic cup These form the substantia propria of the cornea The differentiation of these

[1] Many years ago Kölliker (1861) noted that in birds at a very early period a thin structureless ectodermal membrane is laid down which apparently formed the scaffolding on which the cornea is built Hagedoorn (1928) holds that such a directing membrane (Richtungshäutchen) exists in the anterior vitreous of all vertebrates Mesoderm grows in firstly as the endothelium behind this membrane and secretes Descemet s membrane and secondly as a wedge shaped mass which forms the substantia propria between the epithelium and the primary cornea

See also Laguesse *Arch d'Anat Micros* 1920 xxii Seefelder *Arch f Augen* 1926 xcvii, Mann *Trans Ophth Soc*, 1931 li p 63

cells into the corneal fibrillæ takes place from behind forwards The surface ectoderm forms the epithelium of the cornea

Descemet's membrane is produced about the fourth month by a secretion from the endothelial cells, whereas Bowman's membrane is simply a condensation of the anterior corneal fibrillæ (Seefelder)

As development proceeds the cell content of the cornea diminishes Wandering cells appear about the fourth month

The cornea is transparent from the first as is all early embryonic tissue

The Sclera

The sclera arises through a condensation of the mesoderm round the optic cup The anterior portion is formed first—no doubt associated with the insertion of the eye muscles The limbus is at first much farther back, lying over the ciliary body, but gradually shifts forwards

Elastic fibres appear about the third month, like the collagenous elements, as an intraprotoplasmic formation

Tenon's Capsule *is developed in the same way as the sclera, but somewhat later, and again the anterior portion is differentiated before the posterior.*

The Pupillary Membrane

Of the mesoderm which invades the anterior vitreous, i e the protoplasmic reticulum between the surface ectoderm and the lens, the anterior portion is non-vascular, and, as we have seen, forms the main portion of the cornea

The posterior portion in which vessels develop goes to form the irido pupillary lamina (of Jeannulatos)

The peripheral portion of this unites with the rim of the optic cup to form the iris, while the central portion is the pupillary membrane

The pupillary membrane is thus developed in the mesoderm at the same time as, and behind, Descemet's membrane It consists of numerous anastomosing vessels and a fibrillary tissue between them It forms, in fact, the anterior part of the tunica vasculosa lentis, with the remainder of which it is continuous under the rim of the optic cup As the edge of the pupil grows forwards, however, this continuity is broken The pupillary membrane is nourished, as is the iris, by the long posterior ciliary arteries, and is thus entirely independent of the hyaloid system and continues to develop when the latter is regressing

The pupillary membrane is at first attached to the edge of the pupil, but later comes to arise from the front of the iris This is due to a split in the mesoderm between the sphincteric portion of the iris and the pupillary membrane After the eighth month the pupillary membrane begins to disappear Remains of it may, however, frequently be seen in the new born babe and sometimes persist throughout life They arise from the *anterior* aspect of the iris in the region of the circulus iridis minor (collarette) (see p 171)

The Anterior Chamber

The Anterior Chamber commences peripherally as a slit in the mesoderm between the cornea and iris which gradually travels centrally It is probable that this happens quite late in fœtal life

According to Cirincione who used the freezing method for making his sections an earlier date for the appearance of the anterior chamber is probably erroneous the result of artefacts due to fixation (as in Fig 186)

At birth the anterior chamber is still very shallow

The region of the future angle is at first filled with loose mesodermal tissue (uveal framework of H Virchow) which later disappears except for the portion

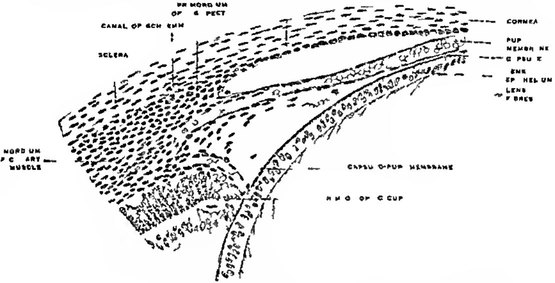


Fig 198—Region of the Angle of the Anterior Chamber in an 88 mm Human Embryo
(From Seefelder in the Kurzes Handbuch)

at the extreme periphery The canal of Schlemm is present at three months and from the first carries blood corpuscles (Seefelder)

The Uveal Tract

The choroid ciliary body and iris are partly mesodermal partly ectodermal in origin They are formed from the anterior portion of the optic cup and the mesodermal and vascular covering of the whole cup

The mesodermal portion of the uveal tract depends for its development on the secondary optic vesicle especially on its pigment layer (von Hippel) Normally it covers the optic cup from the papilla to the pupillary margin and should any portion of the cup be missing the mesoderm does not develop and a coloboma results

The Iris

The Iris is formed from the anterior portion of the optic cup and the mesoderm, which covers it. The neural ectoderm gives rise to the sphincter and dilatator pupillæ and to the posterior epithelium; the mesoderm forms the stroma and the vessels.

Up to the end of the third month of embryonic life there is no true iris, and the margin of the optic cup extends but a little way beyond the equator of the lens (Fig. 186). The retinal and mesodermal portions are continuous with those of the ciliary body without line of demarcation, and moreover, the mesodermal portion is not delimited from the pupillary membrane.

The development of the iris as such commences about the middle of the fourth month by a forward growth of the rim of the optic cup with its overlying mesoderm. It is preceded by a spur-like process of mesoderm (Fuchs), to which is attached the pupillary membrane.

The iris thus becomes more or less differentiated from the ciliary body and pupillary membrane.

At this period a space, *the ring sinus of von Szily*, is present between the two layers of ectoderm forming the rim of the optic cup. It represents the last trace of the cavity of the primary optic vesicle and disappears about the seventh month.

The sphincter pupillæ is developed at this period from the pigment epithelium of the rim of the optic cup. *It is thus curious, as Nussbaum first pointed out, in being a muscle derived from ectoderm.* It becomes limited laterally by a ridge of pigment known as Michel's spur.

At about the sixth month the sphincter begins to separate from the cells that gave it origin, passes into the mesodermal portion of the iris and is invaded by vessels. Numerous connections with the pigment epithelium however, always persist, and Michel's spur represents the most lateral of these. Pigment cells, derived from the anterior portion of the optic cup pass through the sphincter and into the iris stroma to form *the clump cells* (Fig. 19).

The dilatator pupillæ is also derived from the same ectodermal cells at the end of the sixth month.

Whereas a whole cell of the anterior layer goes to form a muscle fibre of the sphincter pupillæ, only part of it forms a fibre of the dilatator.

The anterior epithelium already contains pigment when the iris commences to form. Pigmentation of the posterior epithelium commences at the pupillary margin, and reaches its base at about the sixth month.

The iris develops in width more slowly than the rest of the eye; so the pupil gets wider up to the beginning of the seventh month. At five months the iris is hidden by the limbus and resembles the condition of aniridia.

After the eighth month the pupil becomes smaller, due to the development of the sphincteric portion of the iris. With the disappearance of the pupillary

membrane changes take place in the front of the iris with the formation of iris crypts At about this time the *anterior border or limiting layer* can be recognised It is formed by several rows of star shaped cells which anastomose with each other and which may at times contain pigment cells at birth

The pigmentation of the stroma usually takes place in the first years after birth and appears to be under the control of the sympathetic system Also the pattern of the anterior surface of the iris is produced during the first year and generally the iris is not fully formed till twelve months after birth

The Ciliary Body

The neural ectoderm forms the epithelium of the pars ciliaris retinæ while the mesoderm is responsible for the stroma the ciliary muscle and the vessels

The ciliary body is demarcated from the true retina by the formation of the ciliary folds at the beginning of the third month Vessels sink into these folds and form what is for the most part a venous net At the sixth month the ciliary arteries have formed the circulus iridis major and given off branches to the pupillary membrane the stroma of the iris and the ciliary region

During fœtal life the most anterior of the ciliary folds lie behind the peripheral portion of the iris and then gradually move backwards

The longitudinal portion of the ciliary muscle is formed from the mesoderm next the sclera at the fourth month while the circular portion develops at the end of the sixth month

At first only the corona ciliaris is present The pars plana is formed at the fifth month by the limit of the true retina i e of the pars optica moving backwards towards the equator By this too the original small teeth of the ora serrata are lengthened

The Choroid

The primitive choroid is developed in the mesoderm round the primary optic vesicle which it clothes as a vascular venous net It is thus a very early formation (Fig 186) It gradually divides into two and then more layers of vessels

By the fifth month all the layers of the choroid can be recognised

By the sixth month the elastic lamina is present

The time of pigmentation of the choroid varies The pigment is developed in the melanoblasts or fixed cells of the choroid somewhere towards the end of fœtal life and first in the neighbourhood of the posterior ciliary arteries

The final anatomical relationships between the three coats of the eye are determined by function rather than by embryonic origin

Thus the corneo sclera and the uveal tract derived from the same mass of

mesoderm are separated from each other in the adult eye anteriorly by the anterior chamber and posteriorly by the suprachoroidal space

They are only attached where the ciliary muscle arises from the scleral spur and at the optic nerve

On the other hand the uveal tract is closely connected with the inner coat

Thus the pigment layer of the retina derived from the outer layer of the optic cup rarely separates in the living from the choroid and never from the ciliary body

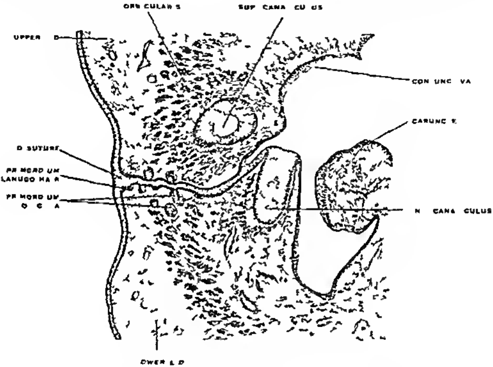


Fig 199 —Section of the Joined Lids of an Embryo of 14 cm × 45 (After Fuchs)

Thus also the anterior layer of the pars iridica retinæ is inseparably connected with the iris as are also the sphincter and dilatator pupillæ which are derived from it

The Lids

The lids are developed at the beginning of the second month as two folds of surface ectoderm which grow towards each other from above and below the eye respectively

They meet and unite loosely at two and a half months (Figs 186 199) union taking place from the edge towards the middle At about the fifth month they separate again through keratinisation of the cells of the united edges

Moll's, Zeis's, and the Meibomian Glands are developed about the end of the tenth week by the ingrowth of solid columns of ectodermal cells from the lid margins These later acquire a lumen

The Tarsus is formed as a condensation of the mesoderm of the lids

The first hairs of the eyebrows make their appearance when the lids unite They are the first hairs of the embryo (Contino)

The cilia appear a little later first in the upper lid and then in the lower

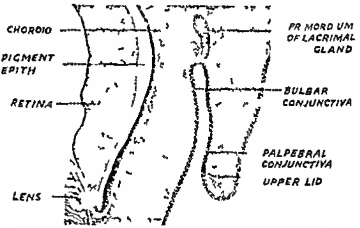
The Lacrimal Gland is developed by epithelial buds which grow towards the end of the second month from the upper and temporal side of the conjunctival sac (Fig 200) and repeatedly divide With the development of the levator and Tenon s capsule the gland is divided into orbital and palpebral portions

Krause s glands are developed as growths of the basal cells of the upper conjunctival fornix and to a slight extent from the lower fornix

The Lacrimal Ducts —The primordium of the tear ducts lies in a solid column of cells which derived from the surface ectoderm sinks into the furrow between

FIG 200—SAGITTAL SECTION OF THE OUTER PORTION OF THE UPPER LID OF AN EMBRYO OF 34 MM

(From Poirier after Contino 1909)



the lateral nasal and maxillary processes This grows upwards into the lids to form the canaliculi and downwards into the nose The lower canaliculus grows farther laterally than the upper Hence the lower punctum is lateral to the upper

Errors in development such as multiplication of the canaliculi or puncta and abnormal diverticula arise from abnormal division or outgrowths of the primitive solid column of cells

Canaliculisation of the solid columns of cells takes place by a degeneration and shedding of the central cells (Fig 201) first in the region of the lacrimal sac The debris of these cells may cause blocking of the nasal duct *and give rise to a mucocele not uncommon in the first few weeks of life*

The Conjunctiva is developed from the ectoderm lining the lids and that covering the globe (Figs 186 200)

The Lacrimal Caruncle —According to Ask the caruncle is developed by the cutting off of a portion of the lower lid by the ingrowth of the lower canaliculus

The Semilunar Fold develops from the conjunctiva at about five and half weeks

THE VITREOUS

The development of the vitreous [1] has been the source of a great deal of dispute Some hold that it is purely mesodermal, others that it is ectodermal in origin It is probably derived from both

We may divide the development of the vitreous into three stages

(a) The primary vitreous
(b) The secondary vitreous
(c) The tertiary vitreous

The Primary Vitreous —Between the lens and the inner layer of the optic cup there are fine protoplasmic filaments (embryonal supporting tissue of von Szily) derived from both the surface ectoderm of the lens and the neural ectoderm of the optic cup

These are invaded by mesodermal cells and by the hyaloid system of vessels derived also from the mesoderm

The Secondary Vitreous.—At the 13 mm stage the lens epithelium secretes its hyaline capsule, and from this period takes no more part in the development of the vitreous The glial fibres of Muller at this stage do not end at the internal limiting membrane, but are continued beyond this to form the secondary vitreous

At the same time the hyaloid system of vessels is developing, and when these regress, the primary (vascular) vitreous is pushed by the secondary avascular vitreous into the centre of the eye and into the region behind the lens A line of condensation forms between the primary and secondary vitreous, and this constitutes the wall of Cloquet's canal and the "anterior part of the hyaloid membrane"

Tertiary Vitreous.—After the third month the ectodermal part of the ciliary body and iris also secretes vitreous fibrils, some of which go to form the suspensory ligament of the lens and the so-called "lateral portion of the anterior part of the hyaloid membrane" It will thus be seen that the main part of the adult vitreous is derived from the neural ectoderm of the inner layer of the optic cup That portion behind the lens and surrounding Cloquet's canal is derived from the lens ectoderm and from the mesoderm

POST NATAL DEVELOPMENT OF THE VITREOUS

At birth Cloquet's canal extends horizontally backwards from a point a little below and to the nasal side of the posterior pole of the lens

The extreme anterior end of the main trunk of the hyaloid artery extends horizontally backwards from the lens capsule along the first part of the canal After birth the remains of the artery curl up like a corkscrew and hang down behind the lens The walls of Cloquet's canal become very lax and hang down, moving with the movement of the eye and head (Mann), its attachment to the back of the eye probably remains as the arcuate line

[1] See Mann 1927–28, also, Mawas and Magitot, 1912, and Redslob 1932

The Hyaloid System of Vessels

At the stage of the secondary optic vesicle two sets of vessels can be made out one inside the vesicle, the other on its surface

(*a*) The hyaloid artery, a branch of the ophthalmic, *enters* the vesicle viâ the fœtal cleft, and drains anteriorly into the annular vessel It also anastomoses with the vessels of the optic stalk

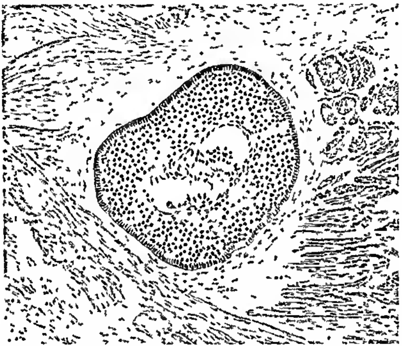


Fig 201 —To show the Formation of the Lumen in the Lachrymal Canaliculus of a Fœtus of about Eight Months

The debris of the central cells may at times cause the mucocele not uncommon in the first weeks of life Around are fibres of the orbicularis

(*Author's preparation*)

(*b*) A second set ramifies *on the surface* of the secondary optic vesicle and will eventually form the choroid (*q v*) The most anterior part of this plexus forms the annular vessel round the rim of the cup

Fuchs called it the *annular artery*, but although it is impossible at this stage to differentiate arteries and veins structurally, it is most probably a vein since the hyaloid artery drains into it

The circulus iridis major is later developed in the same position as the annular vessel but is not derived from it

The hyaloid artery divides repeatedly, and gradually forms a network of vessels covering the back of the lens (the tunica vasculosa lentis) Other branches of the

artery practically fill the vitreous chamber at this stage and reach their greatest development at the middle of the third month (vasa hyaloidea propria) (Fig. 186).

The hyaloid artery at first emerges from the middle of the nerve head (Figs. 202, 203, 204), but later is shifted more and more to the nasal side. It at the same time becomes smaller and smaller, while the arteria centralis grows

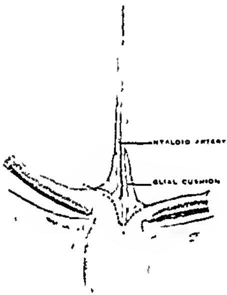


FIG. 202.—THE ENTRANCE OF THE OPTIC NERVE IN A 180 MM. HUMAN FŒTUS

The dotted line indicates the amount of atrophy to form the normal physiological cup

(From Seefelder, in the Kurzes Handbuch.)

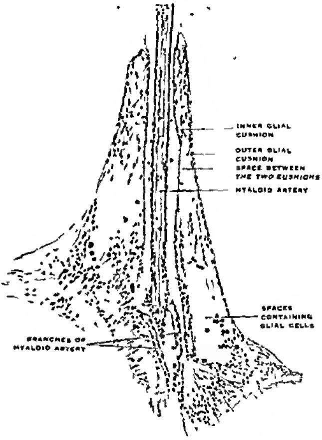


FIG. 203.—THE REGION IN FIG. 202 ANTERIOR TO THE DOTTED LINE, ENLARGED.

(From Bach and Seefelder, in the Kurzes Handbuch.)

larger. Eventually the hyaloid artery appears to be a twig arising from the central retinal artery.

The hyaloid system of vessels disappears first at the peripheral parts of the vitreous (about the fifth month), and concurrently with this the point of division of the main hyaloid artery shifts farther forwards and its attachment to the lens farther medial.

The venous return of the whole system is viâ the capsulo-pupillary membrane, which covers the lens from its equator to the edge of the pupil.

The Blood-supply of the Optic Nerve and Retina

At first the optic nerve and retina have no vessels, as the hyaloid system supplies the developing lens and the vitreous only. At two and a half months with the invasion of the septal vessels a plexus of veins forms round the hyaloid artery while it is still in the optic nerve In this, two vessels can be distinguished early, and these unite near the nerve head to form the vena centralis retinæ. After this, at about three and a half months, the retinal arteries are developed as two buds from the hyaloid artery which grow into the nerve fibre layer of

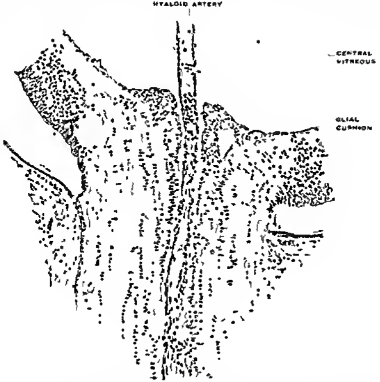


Fig 204 —Horizontal Section of the Optic Nerve Entrance of a 75 mm Human Embryo

(From Bach and Seefelder, in the Kurzes Handbuch)

the retina and later become canaliculised. Similar buds form the retinal veins

The vessels gradually grow out towards the ora serrata, and at the eighth month the vascular arrangements of the retina are complete.

That portion of the hyaloid artery enclosed in the optic nerve becomes the arteria centralis.

The Orbit

The orbit is formed in the mesoderm around the eye. This mesoderm is, however, derived from several sources

1 Above, from the mesodermal capsule of the fore-brain
2. Below and laterally, from the maxillary process.
3. Medially, from the fronto-nasal process , and
4. Behind, from the pre- and orbito-sphenoids.

The optic vesicle at first lies at the side of the head between the head fold and the maxillary process. As the maxillary process grows forwards and forms the floor and lateral wall of the orbit the eye passes forwards too. The fronto nasal process divides into two lateral and two medial nasal processes.

Each lateral nasal process goes to form the inner wall of the orbit (including the fronto nasal process, the lacrimal and ethmoid bones) of its side and eventually unites with the maxillary process.

The roof of the orbit is formed from the capsule of the fore brain.

The optic nerve passes into the eye between the two roots of the orbito sphenoid which are attached to the orbito nasal septum.

All the bones of the orbit (including the great wing of the sphenoid) are membrane bones, but the pre and orbito sphenoids belonging to the base of the cranium are developed in cartilage.

As it is formed round the eye the orbit is at first much more of a sphere than in the adult, and also the orbital opening is more circular.

The eye at first grows faster than the orbit, whose margin at six months only reaches to the equator.

The Extrinsic Muscles

The extrinsic muscles of the eye are developed by a condensation of the mesoderm round the eye. At first (at 7 mm.) they form one mass which Lewis (1910) found was supplied by the 3rd nerve only. Later (at 9 mm.) when the 4th and 6th nerves enter this mass divides into separate muscles. The levator does not separate from the superior rectus till the 55 mm. stage.

According to Seefelder the muscles grow from behind forwards, which accounts for the numerous variations in their insertions and constancy of origin.

Summary of the Origin of the Various Tissues of the Eye (from Mann (1928))

Surface Ectoderm gives rise to
- Lens
- Epithelium of cornea
- Epithelium of conjunctiva (and hence) lacrimal gland
- Epithelium of lids and its derivatives and cilia, the Meibomian glands and the glands of Moll and Zeis
- Epithelium lining lacrimal apparatus

Neural Ectoderm gives rise to
- Retina with its pigment epithelium
- Epithelium covering ciliary processes
- Pigment epithelium covering posterior surface of iris
- Sphincter and dilatator pupillæ muscles
- The optic nerve (neuroglial and nervous elements only)

Adhesions between Surface and Neural Ectoderm give rise to
- Vitreous
- Suspensory ligament of lens.

Associated Paraxial Mesoderm gives rise to

The blood vessels, i.e. the choroid, the arteria centralis retinae, ciliary vessels and other vessels of the orbit which persist, as well as the hyaloid artery, the vasa hyaloid propria, and the vessels of the vascular capsule of the lens which disappear before birth

The sclerotic

The sheath of the optic nerve

The ciliary muscle

The substantia propria of the cornea, and the endothelium of its posterior surface

The stroma of the iris

The extrinsic muscles of the eye

The fat, ligaments and other connective tissue structures in the orbit

The upper and inner walls of the orbit

The connective tissue of the upper lid

Visceral (Mesoderm of Maxillary Process) below the eye gives rise to

The lower and outer walls of the orbit. The structures lying behind and below the eye (i.e. the alisphenoid, malar and orbital plate of superior maxilla)

The connective tissues of the lower lid

A list of age length relationships[1] at representative stages is added for reference (crown rump length in mm)

4 weeks	(28 days)	7.8 mm	11 weeks	(77 days)	59.2 mm
5	(35)	12.2	12	(84)	70.5
6	(42)	17.6	16		130.0
7	(49)	24.0	24		190.0
8	(56)	31.5	30		250.0
9	(63)	39.6	36		310.0
10	(70)	49.0	40		310.0

The Eye at Birth

The eye at birth is less of a sphere than in the adult. This is due to the bulge of the postero lateral quadrant

Its antero posterior diameter varies from 12.5 to 15.8 mm, and the vertical diameter from 14.5 to 17 mm. To offset the comparative shortness of the eye which would make it exceedingly hypermetropic, the media are more highly refractive than in the adult, the seat of the excess of refractivity being in the lens (Fuchs[2])

The cornea is relatively large, its diameter (10 mm) being three fifths that of the antero posterior axis

It is more curved at the periphery than at its centre, i.e. just the opposite of the condition in the adult (Merkel and Orr)

The internal rectus is very close to the cornea

The corneal stroma contains more nuclei than in the adult

The stroma of the uveal tract has no pigment except possibly posteriorly near the optic nerve

[1] From Mann, 1928

[2] Weiss, however, gives the following measurements for the antero-posterior, vertical, and transverse diameters respectively, 18.4, 15.4, 16 mm

The pigmentation of the anterior border layer of the iris commences in the first few days of life

The pupil is small and does not dilate fully

The anterior chamber is shallow and its angle is narrow

The ligamentum pectinatum is still somewhat fœtal in character i e it still fills the angle to a large extent

The ciliary processes are still in contact with the iris

The stroma of the ciliary body is very cellular but the various types of muscle can be recognised

The ridges of the ciliary processes are as dark as the valleys between them

The macula is as far from the disc as in the adult A depression in it is just visible The cones are still short and stumpy

The teeth of the ora serrata are just visible (Hess) and the retina passes much more gradually into the pars ciliaris The two nuclear layers fuse and are continued into the ciliary epithelium

A fold of the retina at the ora serrata is often found (Lange's fold) but this must be regarded as an artefact

The orbiculus ciliaris is very short so that the retina lies just behind the ciliary muscle

The nerve fibres behind the lamina cribrosa are still not medullated

The lens is rounder than in the adult and on account of its anterior bulging the anterior chamber is shallow

Post natal Growth and Changes in the Eyeball

The eye grows rapidly in the first years of life the vertical diameter growing faster so that the eye becomes more nearly spherical The rate then decreases till puberty when it again becomes more rapid till the early twenties (Weiss)

There is a distinct parallel between the growth of the eye and that of the brain Thus from birth to adult life the eye grows 3 25 times and the brain 3 76 The body on the other hand increases 21 70 times

The increase in size during the first years of life affects mainly the anterior segment i e the cornea and the sclera up to the insertions of the muscles

Thus the cornea reaches adult size at about two years or earlier

The later growth affects mainly the posterior segment, but the distance between the fovea and optic nerve remains the same as at birth

Medullation of the optic nerve is completed in the first three weeks after birth, and seems to be hastened by exposure to light Thus a premature baby will have its medullation farther advanced by the time it reaches the nine months than a newly born full term child

The fovea is not properly developed till one month after birth

There is little difference between the ciliary and pupillary zones of the iris at birth. This can be made out at about six months

The colour of the iris changes in the first few years of life depending on the amount of stroma pigment laid down

The Ciliary Body—As the retina recedes so there is an increase in the size of the pars plana. The line of demarcation between the retina and ciliary body is well marked but does not reach adult relationships till about seven years

As the ciliary processes are displaced backwards the angle of the anterior chamber widens to adult size between two and four years

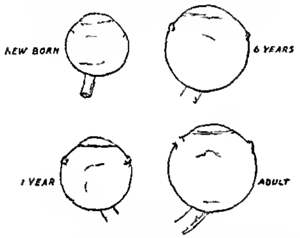


FIG 205—GROWTH OF THE EYE AFTER BIRTH

From Power after Wei

There is no muscle of Müller at birth (Fuchs). It is only after the fifth year that the ciliary muscle and thus the whole ciliary body takes on a triangular form

The lens grows rapidly in the first years of life and becomes flatter owing to being pulled on by the ever widening circle formed by the ciliary body. The lens continues growing throughout life (p 111)

The eye of the new born child is normally hypermetropic. The increase in axial length would however, render it myopic were it not for this flattening of the lens

The eyes get farther apart and the orbits enlarge especially anteriorly so that their temporal borders are more widely separated. As the eyes separate they also tend to diverge since the separation makes the external rectus act to greater and the internal rectus to less advantage than before (Fuchs)

SIGNS OF AGE IN THE EYEBALL

The cornea flattens with age, but more in the vertical than in the horizontal meridian. This gives rise to an astigmatism against the rule. *Hence the onset*

of astigmatism against the rule in emmetropes after about forty years may be regarded as normal, and, further, for the same reason, astigmatism with the rule tends to lessen and that against the rule tends to increase with age

The arcus senilis is a manifestation of the fatty degeneration which tends to take place with age throughout the fibrous tunic of the eye

It starts above and below as two grey crescents, close to and parallel with the corneal margin The crescents eventually fuse and become whiter and more opaque The ring so formed is thicker above than below There is always a portion of clear cornea between it and the limbus It is sharply defined peripherally, but fades more gradually into clear cornea centrally

The fatty degeneration affects first the superficial layers of the stroma and Bowman's membrane Peripherally it is limited by a line passing from the end of Bowman's membrane obliquely outwards for a varying distance into the sclera

The sclera becomes thicker and more rigid There is a tendency for the deposition of fat, which changes the colour from white to yellowish

In the uveal tract there is a great increase in the amount of connective tissue The ciliary body, therefore, thickens and the circumlental space is diminished. Senile myosis and rigidity of the sphincter pupillæ are also due to increase in the amount of connective tissue in its neighbourhood

The various glass like membranes become thicker, and there is a great tendency to wart formation seen specially at the periphery of Descemet's and in the hyaloid membrane (membrane of Bruch)

The warts on the hyaloid membrane are secreted by the pigment epithelium which covers them, but thins over the summits of the elevations They, therefore, appear with the ophthalmoscope as yellowish white spots surrounded by a narrow pigmented border The spots in Tay's choroiditis are of this nature

The pigment epithelium tends to show areas of atrophy, especially round the disc

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CHAPTER X

COMPARATIVE ANATOMY

Response to the light stimulus does not in itself indicate an organ of vision We know that many inorganic substances react to light One of the most remarkable examples of this is seen in the photographic plate Also, as is well known, a colourless solution of eserine goes pink when exposed to light

Plants, too, respond to light Thus the portions above ground as a rule grow towards the light (positive phototropism) while the roots grow away from it (negative phototropism) Also the formation of chlorophyll, the hæmoglobin of plants, depends on the presence of light but we do not postulate an organ of vision.

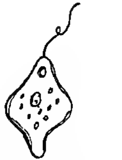


Fig 206 —Euglena viridis (a Flagellate) with its 'Eye spot'

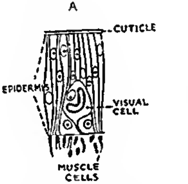


Fig 207 —A Section—A Visual Cell and Epidermis of the Worm Stylaria lacustris

(From Butschli after Hesse)

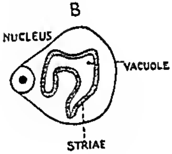


Fig 208 —B The Visual Cell under Greater Magnification

In the unicellular animals (amœbæ infusoria) the animal usually reacts as a whole in its response to light, thus the amœba crawls away from a beam of light thrown on it On the other hand, *Paramœcium bursaria*, which contains algæ, swims towards the light which is necessary for its symbiotic chlorophyll-containing partners to build up starch and sugar But even in the protozoa there may be some specialisation Thus Engelmann found that the anterior portion of *Euglena viridis*, an infusorian, is much more sensitive to light than the posterior In this anterior portion he described an "eye spot" which at first he thought was the most primitive eye But later he found that the area most sensitive to light was in front of this In stentor, another protozoon, the anterior end also is especially susceptible When light falls on this part, the animal turns away and seeks a shady corner

In the multicellular animals **(metazoa)** there is further specialisation In the earthworm, for instance there are specialised visual cells first described by Hesse in 1895 and since found in many other animals Each cell is shorter and wider than the other epithelial cells among which it is placed , also, the protoplasm is

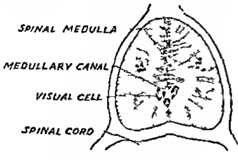


FIG 209 —SECTION OF THE SPINAL CORD OF AMPHIOXUS

(From Poirier after Hesse)

FIG 210 —VISUAL CELL OF AMPHIOXUS

clearer and contains vacuoles at its proximal end it is continued into a filament probably a nerve fibril (see also p 327)

Earthworms are sensitive to bright light and crawl away from it They come out of their burrows before dawn to feed but at break of day, they return The return to the burrow is simply an expression of negative phototropism

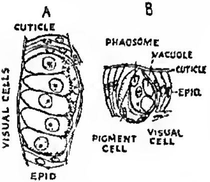


FIG 211 —THE EYE OF STYLARIA LACUSTRIS

A = on transverse section
B = on horizontal section
(From Bütschli after Hesse)

In passing up the animal scale, we find that to arrive at true vision we pass through three stages

(*a*) **Phototropism** —The animal as a whole moves either towards or away from the source of light (positive or negative phototropism), as we saw in the *Paramœcium bursaria* and amœba

(*b*) **Sensation.**—Here the animal receives the light stimulus by a special mechanism, but does not recognise it as light As an example of this, we saw how the earthworm avoids sunlight Also the tubeworm rapidly withdraws its feathery tentacles (each of which is possessed of an ' eye ') when the light falling on it is shaded This " shading reaction " (an expression of negative phototropism) is present in many sluggish and sessile shore creatures It is obviously protective A fish in search of food casts a tell tale shadow This shadow will cause barnacles to close,

sea squirts to contract up into gelatinous blobs and burrowing bivalves to withdraw their soft protruding syphons into the sand On the other hand a sudden shading of the light will cause the sea urchin to bristle up its spines Thus this shading reaction enables the invertebrate to hide or arm itself at the approach of its enemies

(c) **Specific Sensation** —Here the animal owing to the development of the central nervous mechanism of vision recognises the light as light It is only animals which have the last type of vision which really *see* in the true sense of the word

CLASSIFICATION OF THE TWO BIG GROUPS OF VISUAL ORGANS

A The epithelial eye of invertebrates developed from the skin
- Simple eye
  1 Single epithelial cell
  2 A collection of epithelial cells
     (a) Flat
     (b) Cup shaped
     (c) Vesicular
- Compound or faceted eye

B The cerebral eye of vertebrates developed from the central nervous system

A The most rudimentary eye is the visual cell This as we have seen is an epithelial cell but slightly differentiated and well seen in worms

In the next stage we find a mantle of pigment associated with the cell (Fig 210) The pigment is there to absorb the light and to convert it into heat and possibly other forms of energy In amphioxus these visual cells lie deep next the medullary canal (Fig 210) A further stage is seen in the worm *Stylaria lacustris* in which a number of these cells have become grouped together (Fig 211) Such a rudimentary eye whether consisting of one or more cells is called an ocellus (= little eye)

(2b) **Cup shaped Eyes** —In these the visual cells of the surface epithelium have sunk in so as to line a fossa or cup Thus we have a greater crowding together of visual elements and a better

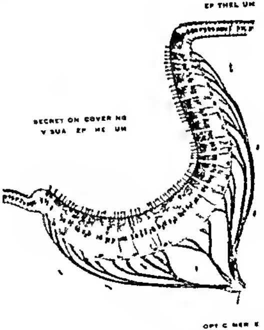


FIG [illegible] —THE EYE OF PATELLA—A MOLLUSC (STILL WIDE OPEN ON TO THE SURFACE)
The visual epithelium consists of pigmented visual cells and non pigmented secretory cells
(From Hesse.)

orientation of the incident light They have (as we say in certain cases of cataract) fair projection *(yeux à direction)*

These eyes, although superior to the flat eyes, and although they have arrived at a certain degree of differentiation, consist almost exclusively of visual cells They form a simple depression, open widely on the surface (Fig 212) A further advance is seen where the opening is more or less closed, the "eyes" then opening on the surface by a small hole or "pupil" only (Fig 215) These latter are formed on the principle of the pin hole camera—i e a dark chamber with a small hole leading into it

A further stage is seen where, apart from the visual cells, a kind of lens formed by the cuticle is present and between the lens and the retina a kind of vitreous

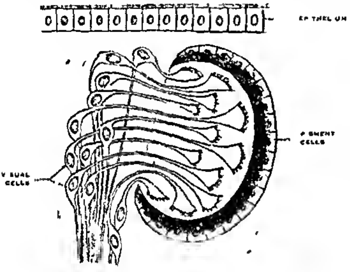


FIG 213 —THE EYE OF THE WORM PLANARIA GONOCEPHALA

The free end of the visual cells bears cilia and passes into the crescent formed by the pigment cells

(From Hesse)

substance This is formed by secretory cells placed among the visual cells (Fig 217)

Cup shaped eyes are seen in the arthropods and molluscs

(2c) **Vesicular Eyes.**—This is a further stage in development Here, the opening in the depression is closed so that the eye forms a vesicle, which sinks in from the surface and becomes covered over by surface epithelium (Figs 218, 219)

Such eyes are seen in the ocelli of spiders and scorpions and in cephalopods, which have the most differentiated invertebrate eye Nautilus, a cephalopod, however still has a simple cup shaped eye which opens on the surface (Fig 215)

In the cephalopods (Fig 221) the eye is partially contained in a cartilaginous orbit The proximal (deepest) part of the vesicle forms the retina, the distal part is responsible for the posterior portion of the lens The surface ectoderm becomes thickened to form the anterior portion of the lens (which joins the posterior part)

and is so folded that it forms a kind of iris pupil cornea and anterior chamber which is open at one point to the surrounding fluid in which the animal lives The mesoderm between the optic vesicle and the ectoderm forms two laminæ of cartilage (equatorial and iridic) and outside these is formed the silvery membrane or tunic which passes forwards to the pupil Ciliary and iridic muscles are also found, so that accommodation and pupillary movements are present

The Compound or Faceted Eye is found in the arthropods, especially in the

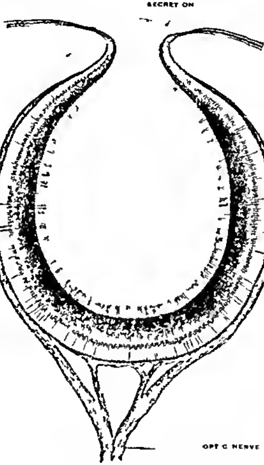


FIG. 214.—THE EYE OF THE SNAIL HALIOTIS
(The opening is much narrower than in Fig 213)
(*From Hesse*)

crustaceans and insects It is formed by the union of a number of modified ocelli Each ocellus which goes to form such an eye is called an ommatidium (resembling an eye) The number of ommatidia varies from one to many thousands

An ommatidium usually consists of the following the dioptric apparatus is formed by a corneal facet and a lens cone Behind this are the retinal elements, usually four to eight to each corneal facet forming a *single* unit, from which a single nerve fibre passes to a collection of nerve cells the optic ganglion

It is the fact that in the ommatidium a number of retinal elements are structurally and functionally united to form a single unit, *the retinule*, which distinguishes it from the ordinary ocellus

The whole eye usually forms a portion of a sphere and on section is fan shaped

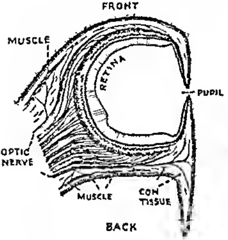


FIG 215 —THE EYE OF NAUTILUS A CEPHALOPOD
(From Bütschli)

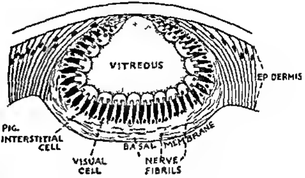


FIG 216 —THE EYE OF THE CARNIVOROUS WORM, NEREIS CULTRIFERA
(From Bütschli after Hesse)

The surface, which is formed by the corneal facets united together, appears smooth to the naked eye, but under the loupe or microscope it forms a mosaic

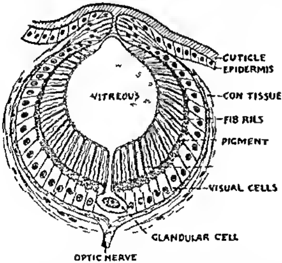


FIG 217 —THE EYE OF THE WORM, PHYLLODOCE LAMINOSA
(From Bütschli after Hesse)

The facets are hexagonal in the insects, quadrilateral in crustaceans, and convex in butterflies

B **The Vertebrate or Cerebral Eye** —Unlike that of the invertebrate, the vertebrate eye is remarkable for the uniformity of its development and general structure

Generally speaking, the cerebral eye consists of a retina, a dark chamber, and a dioptric apparatus

There are, however, exceptions, such, for instance, as in the cyclostomes, *Proteus anguineus*, amphioxus, ascidia, the mole, and others.

In the cyclostomes generally the eye is a simple vesicle under the skin ; only in the adult lamprey is it more developed, and one finds traces of a lens, cornea,

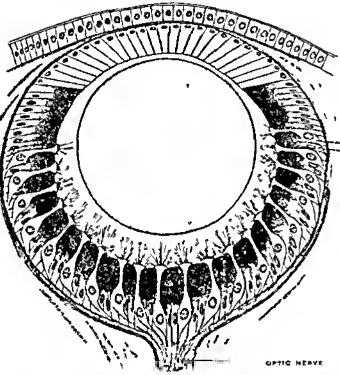


FIG 218 —THE EYE OF THE SNAIL, HELIX POMATIA (completely cut off from the surface).
(From Hesse)
The visual cells have cilia The space between the lens and retina is filled with secretion.

and iris. In the larva of this animal the lens is still a vesicle. The myxinoids have no lens.

The Proteidæ or amphibian urodeles are cave-dwellers In them the eye is also a simple vesicle under the skin and does not contain a differentiated refracting apparatus. The eye has no orbital cavity (Configliachi and Rusconi), and is practically hidden in the masseter muscles. It is very rudimentary, about 0·5 mm in diameter, and seen with difficulty as a dark shadow under the skin.

In the mole the eye is more differentiated, but is still very small, being about 2 mm in diameter. It is practically covered by the skin, in which there is always, however, a small hole (Ciaccio). This varies from 0·125 to 0·975 mm. in the *seeing* mole (*Talpa Europa*), to 0·50 to 0·20 in the blind mole (*Talpa cæca*).

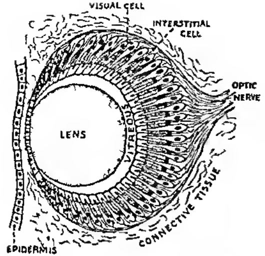


FIG. 219.—SCHEME OF THE CLOSED VESICULAR EYE OF A GASTEROPODE MOLLUSC.
(From Bütschli.)

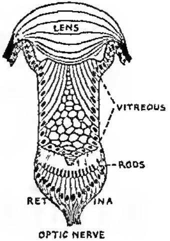


FIG. 220.—SECTION OF THE OCELLUS OF THE SPIDER, SALTICUS.
(From Bütschli after Grenacher.)

At any rate in the latter type the hole is too small for vision, and as was already realised by Dante, the mole sees through its skin.

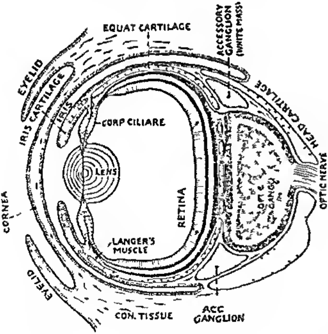


FIG. 221.—SCHEMATIC SECTION OF THE EYE OF A TYPICAL CEPHALOPOD.
(From Bütschli.)

Then there is the *Lancelet* (*amphioxus*) belonging to the acraniate fishes, which really lies between the invertebrates and vertebrates. Its "eyes" are

unicellular ocelli, which are placed next the medullary canal (Figs 209 and 210) and thus far from the surface The light can reach the eyes because the animal is small and transparent

The " eyes " of amphioxus, too are said to lie between the invertebrate and vertebrate types Here the eyes have sunk into the depths, but have not grown back to the surface as do the cerebral eyes

In the larva of ascidia also, a *rudimentary eye is attached to the medullary canal*

Thus in the genesis of the vertebrate eye there are three stages

(*a*) Development of the eye from the surface ectoderm (epithelial eye of invertebrates)

(*b*) The eye sinks in to lie next the medullary canal (amphioxus, larva of ascidia (sea squirt))

(*c*) The eye grows out again to the surface (cerebral eye of vertebrates)

In the epithelial eye of the invertebrates as a rule [1] the light strikes the retinal cells before the nerve and the retina is called a verted or converse retina

In the cerebral eye of vertebrates the retina being produced from the anterior " invaginated " portion of the optic vesicle the light strikes the nerve fibres first, and the retina *is said to be of the inverted type*

The Comparative Anatomy of the Retina

The Retina of the Invertebrates —The *invertebrate retina consists* of visual cells and their processes In the vertebrate retina to these are added the bipolar, the ganglion cells, and supporting fibres

The visual cells of the invertebrate are of two main kinds

(*a*) A cell with a ciliated border or a striated zone (' Stiftchensaum " of Hesse)

(*b*) A rod like cell

The latter is the only form that obtains in the vertebrate retina A third type of visual cell is one with a phaosome or phaosphere i e a large vacuole which undergoes changes when exposed to the light (Fig 211, B)

(*a*) Cells with a Ciliated Border or Striated Zone

The single cell constituting the primitive eye may be ciliated Often the cells contain large vacuoles round which the striæ are arranged (e g in the leech) (Figs 210 222)

The ciliated portion is often enlarged to increase the area of light reception, and, to the same end, the cell may present digitations as in *Tristomum papillosum* (Fig 222)

The nerve fibre leaves the cell opposite the ciliated region and, indeed, according to Hesse, is continuous through the cell with the cilia

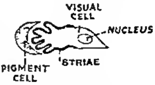


Fig 222 —Eye of Trematode Worm (Tristomum papillosum)

(From Bütschli after Hesse)

[1] Exceptions are seen in the shell fish pecten and in spiders (Fig 226)

(b) Rod like Cell

These are found in many worms in the ocelli of arthropods and in the eyes of molluscs

These visual cells also form the neuro-epithelium of the vertebrate retina and are usually arranged in a single layer But in the mollusc (*Pecten jacobeus*) there are two layers of cells between which are the nerve fibres, and behind the proximal visual cells there is a layer of epithelial cells rich in pigment (Fig 227) In the cephalopods the visual cells are rod like and form a single layer resting on the choroidal cartilage

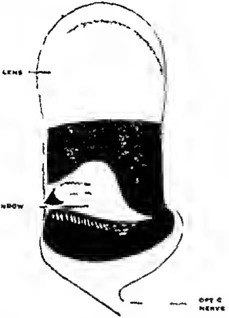


Fig 223 —The Telescopic Eye of Pterotrachea coronata a Mollusc
(*From Hesse*)

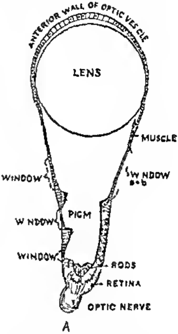


Fig 224 —Telescopic Eye of Pterotrachea coronata on Section
(*From Bütschli after Hesse*)

The nerve fibres leave the eye posteriorly by several holes in the cartilage

Generally speaking the nerve fibres pass into a ganglion which may be directly behind the eye or in the central nervous system

The Retina of the Vertebrates is generally more complex than that of the invertebrates Here we find three neurones The neuro epithelium is nearest the sclerotic

Rods and cones are found in all classes of vertebrates except in certain rudimentary forms Amphioxus is of course an exception, having only unicellular " eyes " (Fig 209)

Some have more cones, others more rods

As we pass up the animal scale, we find more and more rods and cones per sq mm Thus Mann (1928) found in a strip of retina 1 mm long and 0 1 mm

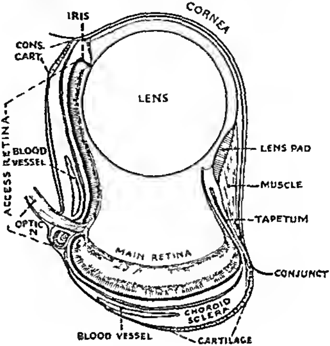


FIG 225 —THE TELESCOPIC EYE OF A DEEP SEA BONY FISH DISOMMA ANALE
(From Butschli after Brauer)

wide 100 cones in the lamprey 125 in the frog, 327 in the hen, while at the human macula there were 652

Generally speaking there are the same layers as in the human

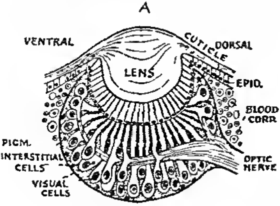


FIG 226 —THE INVERSE EYE OF THE SPIDER TEGENARIA DOMESTICA
(From Bütschli after Widman)

The Pigment Epithelium is much the same in all classes of vertebrates, *but it may contain apart from pig* ment, oil droplets in great variety, and crystals of guanine

The pigment is morphologically different from that of the choroid

In the choroid it is almost entirely amorphous in the retina crystalline (Greeff) In the retina the pigment is epithelial in origin in the choroid mesodermal

In those animals which have a tapetum the retinal pigment in the region of the tapetum is absent

In the outer nuclear layer one finds in certain vertebrates the fibres (massues) of Landolt These are filaments ending in knobs towards the outer limiting membrane and probably derived from the bipolar cells (inner nuclear layer)

The Area Centralis.—In all vertebrates there is found an area where the visual cells are narrower and more closely packed—an area of more acute vision than the rest of the fundus.

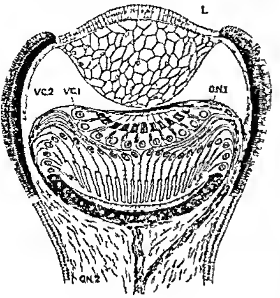


FIG. 227.—THE EYE OF THE MOLLUSC PECTEN JACOBEUS.
(From Hesse.)

L = lens. VC1 = first layer of visual cells. ON1 = nerve fibres from this layer. VC2 = second layer of visual cells. ON2 = nerve fibres from this layer. ON = optic nerve.

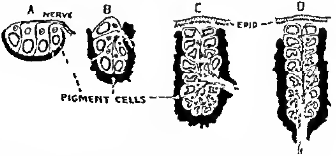
Such an area has even been described in some lowlier animals; for instance, Hess found it in some cephalopods, and a trace of it is seen in certain plathelminths (flat worms), and also in many insects. Now, while these areas result in some advance in visual acuity over the rest of the fundus, it can be nothing like the specialisation first really seen in tarsius. In man and in many monkeys the area is characterised by a yellow pigment, hence the name macula lutea (see p. 67). In the centre of this is found the fovea centralis.

The Retina of Fishes is complex, and differs much in the different species. In general, however, it resembles that of the mammals.

The pigment epithelium is often characterised by numerous granules of guanine (Kuhne), especially in the cyprinidæ, perch, and bream.

These granules may be brilliant white or reddish yellow in colour. They were first described by Della Chiaie in 1836, who called them ophthalmoliths.

FIG. 228.—SCHEMATIC REPRESENTATION OF STAGES IN THE CHANGE FROM THE INVERSE EYE OF CLEPSINE (A) AND NEPHELIS (B) TO THE CONVERSE EYE OF THE LEECH (HIRUDO) (D).
(From Bütschli after Hesse.)



They are abundant, especially in the upper part of the eye, and, from the reflex to which they give rise, have been mistaken for a tapetum.

The rods and cones are very long, so that, especially in the bony fishes, the

neuro-epithelium may occupy one-third to one-half the whole thickness of the retina (Max Schultze). The rods and cones often resemble each other very closely, and Greeff and Max Schultze doubted the existence of the latter in selachians (shark).

The largest cones are found in the perch, where they are often double (Fig. 229, B). Usually there are no oil droplets, but M Schultze found colourless ones in the sturgeon between the outer and inner segments of the cones. A kind of membrane or cloak is often seen round the rods and cones.

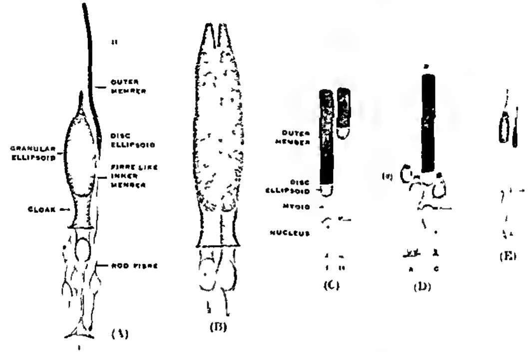


Fig 229.—(A) Rod (II) and Cone (I) of the Perch (B) Large Double (or Twin) Cone of the Perch (C) Red (I) and Green (II) Rods of the Frog (D) Visual Cells from the Retina of a Frog which has been in Strong Light (A — double cone, one part (a) of which has an oil droplet B — rod C cone with oil droplet) (E) Cones of the Sparrow (note oil droplets) (After Greeff)

The outer nuclear layer has four rows usually, but there are six in the bream and one in the lamprey. Many medullated nerve fibres are found

Area Centralis.—It used to be believed that there was no area centralis in fishes, but Carrière showed it in hippocampus and W. Krause in syngnatus, belonging to the lophobranchs. Hess found it in cephalopods, in selachians (scyllium), and in the bony fishes, red mullet and the minnow.

The Retina of Amphibians

Rods and cones are found, the former being usually more numerous.

They are much larger than in the human, the smallest being double the size of ours.

The pigment cells are very large covering eight to fifteen visual cells in the frog They contain numerous oil droplets The frog has two kinds of rods

(a) Violet red the larger and more numerous

(b) Green

The intercalated disc which lies between the inner and outer segments of the rods is better marked than in other animals (Fig 229 C and D) Oil droplets are found between the two segments of the cones They may be colourless or slightly yellow

The visual cells all end in a ramifying footpiece (Generally speaking the cones end in this way and the rods in a knob) Cajal describes double cones and rods

The fibres of Landolt are more numerous than in any other vertebrates

According to Mentz the nerve fibres from the right side of the retina go to the left side of the disc and vice versa The author s own preparations would corroborate this

In *Proteus anguineus* and *Axolotl* (cave dwellers) which belong to the urodele amphibians the retina is primitive and little differentiated and fills practically the whole bulb

The Retina of Reptiles

The retina is generally characterised by the predominance of the cones over the rods The crocodile and gecko are exceptions

The pigment epithelium is like that of the vertebrates generally except in the crocodile where in the upper part of the retina it contains guanine crystals as well as pigment

The cones often contain oil droplets They are abundant and coloured in the tortoise fewer and almost colourless in the lizard

The outer nuclear layer consists of two rows of large cells like those of the amphibians

Both the rod and cone fibres end in a ramifying footpiece and since this is the usual termination of the cone fibres it was believed that only cones were present *Rods and cones are however best distinguished by their connections rather than by the type of termination* (Also by their staining reactions see p 75)

[1] The inner nuclear layer is very wide In the crocodile a horizontally striated area centralis is found In the reptiles the cells of the pars ciliaris retinæ are very large

The Retina of Birds

The retina of diurnal birds contains many cones and few rods In the fowl and pigeon however in a certain area coloured yellow in the former and red in the latter the rods are more numerous

In the nocturnal birds the rods are much more numerous

The neuro epithelium is especially distinguished by the *oil droplets* which are more abundant here than in any other vertebrate The oil droplets are situated

[1] See also I C Mann *Brit Journ Ophth* Jan 1933 *The macula of Sphenodon*

between the inner and outer segments of rods and cones, but more numerous in the latter (Fig 229, E)

In the diurnal birds the droplets are of varied and bright colours Most usually they are red, but there are different shades of yellow, green, and blue In the nocturnal birds the droplets tend to be yellow

The pigments producing these colours were called chromophanes by Kuhne

In the postero superior quadrant of the retina in fowls the yellow droplets predominate and give this area its yellow colour *The same quadrant in the pigeon* is red, giving rise to the red area in these birds The remaining portion of the fundi appears slightly red in fowls and slightly yellow in the pigeon, owing to predominance of these colours in the oil droplets

The fibres of Muller are narrower and in the distal portion of the inner granular layer break up, like those of the reptiles, into a brushwork of fibres

Area and Fovea.—Birds have an area centralis, often two A fovea is often present, and in some including the pigeon and sparrow H Muller found two in each eye

According to Rochon Duvigneaud the insect and grain eating birds which have their eyes more or less lateral and whose visual axes make an angle of 120° or more with each other have a single fovea more or less central The nocturnal birds of prey and the swallow have a double fovea, one central, the other lateral—the latter being placed behind and below the former

In some birds a band shaped area of acute vision may be associated with the macula Where two maculæ are present, these may be joined by such a band (see Casey Wood, 1917)

The Retina of Mammals

A central area is present in practically all mammals, although it is said to be absent in the mouse, rat, and sheep Only man and some monkeys have a true macula and fovea centralis subserving binocular and stereoscopic vision

In tarsius, the sole surviving representative of a group between lemurs and monkeys, there is a great crowding together of the rods in the macular region, but there is no spreading apart of the various layers so that light may fall directly on the neuro epithelium This takes place first in the marmoset (Woollard, 1926)

The Choroid

The choroid *is only seen in the vertebrate eye*, *it is usually* ½ mm *in thick*ness, but in the whale and seal may be greater than 1 5 mm

The pigment is most abundant near its outer part, that is, in the supra choroidal lamina, but is absent here in birds and fishes Thus in the latter the *silvery membrane* (argentea), which is placed between the lamina suprachoroidea and the layer of large vessels, shows through

Sattler in 1876 described in the human (in the macular region) a cellular membrane with elastic fibres which he believed was homologous with the tapetum of mammals

The Silvery Membrane (argentea) of the choroid of fishes (especially of the bony fishes) is placed between the suprachoroidea and the large vessels. It extends over the whole choroid and also over the iris.

It is formed of crystals of guanine which give the membrane its brilliant white appearance, and are responsible for the metallic lustre of the iris of fishes and cephalopods.

The Choroidal Gland.—The choroid of fishes is thicker than that of other vertebrates, and has a spongy structure. It is very vascular, especially in its posterior part. The retina thus appears to rest on a vascular cushion. To this posterior thickened portion the name of choroidal gland has been given. It is particularly well developed in certain ganoid fishes such as amia, and in some bony fishes, for instance the angler fish (lophius).

The Tapetum is seen in most mammals. It is responsible for the green reflex seen in the cat's eye and the emerald green in that of the dog. It is best seen in the carnivores, ruminants, horse, cetacea, seals and dolphin. One also finds it in fishes, but not in rodents, reptiles (except the crocodile), and amphibians.

The (Choroidal) Tapetum may be cellular or fibrous. It may occupy the whole fundus, but more often only the upper and back portion. It is found in the mammals and in certain cartilaginous fishes (skate, shark).

Among birds, only in the ostrich is there a rudiment of the tapetum, but even here it is covered by pigment. The bright reflex from the ostrich eye is (according to Sattler) produced by the lamina vitrea on the inner surface of choroid, which is especially thick in this animal.

The tapetum is placed just deep to the chorio-capillaris, and is visible because this and the retina are devoid of pigment.

Among the carnivores the tapetum is usually cellular, consisting of several layers of flattened cells.

Among the herbivora and dolphins the tapetum is fibrous, i.e. composed of fine fibres, also in several layers. The tapetum reflects the light strongly, and on account of its stratified structure diffracts the light and gives rise to the different colours seen in the fundus.

In the horse the tapetum is extensive; in the lamb and ox it extends especially on the temporal side; in the goat it is quadrilateral and symmetrical round the posterior pole. It is triangular in the roebuck, the dog, and the cat.

In the dog it is usually entirely above the papilla; in the cat it reaches a little below this area. It is brighter in the carnivores than in the herbivores, and is thickest in the ox.

In some animals there is also what is called a *retinal tapetum*. It is formed of crystals of guanine, and occurs in certain bony fishes, especially the perch and cyprinoids (gold fish). It is typical of the bream, and in the crocodile it is of the same nature. In the crocodile[1] the upper portion of the fundus is brilliantly white, but becomes redder in the dark.

[1] Abelsdorff, *Archiv f. A. u. Ph.*, 1905, 1.

We must not forget, however, that in the higher molluscs (cephalopods) and in the bony fishes there is a silvery membrane (argentea), so called because the crystals which it contains give it a silvery brightness.

But this is not a tapetum, for it is placed outside the layer of large vessels and, being covered by pigment, is not seen from the interior of the eye (Ovio).

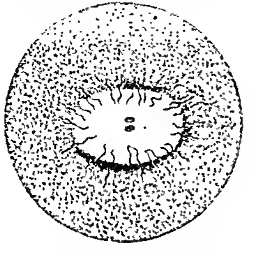


FIG. 230.—THE FUNDUS OF THE HORSE.

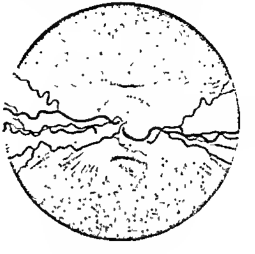


FIG. 231.—THE FUNDUS OF THE RABBIT.

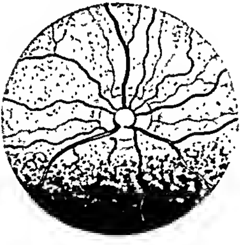


FIG. 232.—THE FUNDUS OF THE DOG. The pale area above is the tapetum.

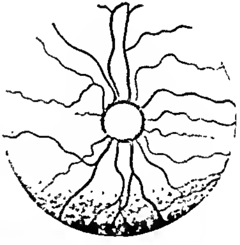


FIG. 233.—THE FUNDUS OF THE CAT. The pale area above is the tapetum.

THE FUNDUS [1]

The Colour.—In those animals which have no tapetum the colour of the fundus comes from the blood in the choroid modified by the density of the pigment epithelium. Otherwise, it is the tapetum which is responsible for the colour.

[1] See Lindsay Johnson, *Phil. Trans.*, 1901, Ser. B., cxciv, pp. 1-82.

A red colour in the fundus is seen in primates (including man, but excluding some lemurs) and also in some insectivores

A yellow colour (principally) is seen in the prosimians, chiroptera in some cats elephants, and squirrels

A green colour is the least frequent it is seen in some carnivora and in the ruminants except the goat and camel in which it is red

In the ox the disc is pink and transversely oval It has no physiological cup, and often remains of the hyaloid artery are seen on it The retina is well vascularised The fundus generally is red but there is a large blurred green tapetum below the disc The fundi of the other ruminants are similar, but the disc is round in the goat semilunar in the sheep and the tapetum is absent in the pig

In the horse (Fig 230) the disc also is transversely oval and has no physiological cup From it numerous small vessels run for a short distance only into the fundus (paurangiotic) The tapetum is greenish blue and above the disc Generally the fundus is reddish grey but varies with the colour of the animal Myelinated fibres are often seen

In the marmot and squirrel the disc forms a longish horizontal band It is kidney shaped in the wolf jackal and fox It is white in lemurs bats rodents edentates marsupials echidna bright red in the hedgehog and mole black or green in the galagos and loris In the carnivores it may be white grey brown maroon, or red

In the guinea pig the disc is small round greyish white and placed in a dark grey retina which is almost devoid of vessels

In the rabbit the disc is pale pink transversely oval and deeply excavated It is continued at the sides into bands of medullated nerve fibres to which the vessels are confined (Fig 231) There are no retinal vessels on the rest of the fundus, but in the albino rabbit the choroidal vessels show through

In the dog the disc is round or triangular It is characterised by a well marked venous ring (Fig 232) The arteries are small cilio retinal and leave the disc at its periphery The tapetum is yellowish green and for the most part in the upper part of the fundus Remains of the hyaloid artery are not infrequently seen

In the cat the disc is grey and round and since the vessels leave it peripherally, it looks something like a glaucoma cup (Fig 233) The bright reddish green tapetum surrounds the disc and occupies the upper part of the fundus Remains of the hyaloid artery are often seen

In birds the fundus is difficult to see owing to the fact that the pupil is small and does not dilate under atropin (Ovio) The disc is hidden by the pecten which is attached to it and its continuation downwards which is known as the cauda

In the pigeon the two foveæ are seen as dark spots

In reptiles the disc is difficult to see owing to the small pupil The hyaloid circulation is visible In the crocodile the disc is black (Hirschberg Abelsdorf)

In amphibians the circulation is visible in the hyaloid system owing partly to the great magnification produced by the lens and partly to the large size of the blood corpuscles

In the frog the disc forms an oblique streak (see Hirschberg)

In Fishes —In the minnow the entrance of the optic nerve is marked by a round disc not well defined which has a wing like prolongation upwards and inwards The vessels converge on the disc and some project into the vitreous

In the eel a papilla is not seen but the nerve entrance is marked by the point of convergence of the whitish nerve fibre bundles and the retinal vessels

In the pike there is a worm like streak provided with pigment from the middle portion of which the nerve fibres radiate No retinal vessels are seen

The selachians have no hyaloid or retinal vessels

Among the bony fishes many have a hyaloid network which Virchow divides into three types

(*a*) The hyaloid artery and vein enter at the ora serrata (ganoids)

(*b*) The artery enters at the papilla and the vein leaves at the ora serrata (gold fish)

(*c*) Both enter at the papilla (eel)

In the cephalopods there are many discs as the optic nerve enters through a number of holes (Fig 221)

The Ciliary Body

In the human eye and that of the higher apes we find the ciliary body formed of two portions

(*a*) Muscular

(*b*) Ciliary processes (essentially vessels)

There is an analogous organ in the cephalopods in which a structure similar to the iris is also seen (Fig 221) but apart from this a ciliary body is only found in the vertebrates in which however it varies greatly The muscular portion is the more constant

The Ciliary Processes are absent or practically so in fishes and amphibians *In birds their number may be 200 as compared with 70 in man*

They may be so large as to leave an impression on the lens In the human the ciliary processes do not touch the lens (0 5 mm away) nor are they in contact with the iris But in some animals such as the rabbit they are in contact a condition which obtains in the human embryo up to the last months

The Ciliary Muscle —In mammals there are two portions

(*a*) Peripheral = muscle of Brucke

(*b*) Central = muscle of Muller

In birds there are three portions the two above and an anterior portion known as Crampton s muscle which is striped

This passes from the deepest layers in the cornea to the anterior part of the

sclera The size of the ciliary body depends on the amount of accommodation and not on the amount of intraocular fluid Thus in man the ciliary muscle is more developed than in other mammals In the ass the amplitude of accommodation is 16D in the dog 2 5 to 3 5D and in the cat only 1D (Hess and Heine) It is feeble in herbivora and rodents who have little power of accommodation but well developed in diving birds and those that fly swiftly for instance, the swallow

In birds (and reptiles) the contraction of the ciliary and Crampton s muscles raises the pressure in the vitreous This pushes on the lens which being held peripherally by the iris can only bulge forward axially In most birds except the nocturnal species the power of accommodation is very great Hess found 40 to 50D in the cormorant

In the bony fishes in which there is only a rudiment of a ciliary body there is hardly a trace of ciliary muscle In fact some authors deny the existence of a muscle and describe a ciliary ligament which binds the ciliary body to the corneo sclera

Fishes whose eyes are normally fixed for near vision have to accommodate for distance This is done by the retractor lentis muscle which pulls the whole lens backwards In some amphibians a high degree of miosis takes the place of accommodation while in others the lens is pulled forwards by the protractor lentis (Hess)

The ciliary muscle and that of the iris in birds and reptiles (sauropsida) are striated while in mammals they are smooth

The Iris

Arthropods—When we speak of the iris of the arthropod we mean the pigment and iridic tapetum Each facet of the compound eye when looked at with the microscope appears to have a pupil surrounded by pigment

Cephalopods have a real iris with pigment and a double sphincter and dilatator

Vertebrates always have an iris It is however rudimentary in some deep sea fishes with telescopic eyes

In fishes the iris has a metallic lustre owing to the crystals of guanine in the silvery membrane which extends into the iris The same applies to the iris of cephalopods Here the membrane is partially covered by chromatophores which give the iris its special colours

The amphibians and reptiles have similar reflexes but it is doubtful whether these are due to crystals of guanine although they are present in the crocodile and chameleon

Among birds the iris is brown in the singing varieties yellow in the birds of prey The heron parrots and pheasants have reddish irides due to oil droplets of different refractions rather than to micro crystals Almost always the iris of birds has a black edge which may make the pupil appear larger than it really is

The musculature of the iris like that of the ciliary body is striped in the sauropsida (birds and reptiles) and smooth in all other vertebrates

In the fishes amphibians and cephalopods the muscles are rich in pigment

In the lower animals there are no iris crypts and the anterior epithelium is well marked

The pupil when constricted is not always round when dilated it is always more or less circular It is round as in the human in birds except the owl in many reptiles and fishes and even in some amphibians

The pupil is oval with the long axis horizontal in the horse ox goat kangaroo and in certain fishes oval with long axis vertical in the seal and alligator vertical slit in the cat fox and owl

In nocturnal selachians such as scyllium torpedo etc it is a slit

Reptiles —*The pupil* in the cephalopods is horseshoe shaped and in some species on contracting it forms a straight or curved line which however remains open at the extremities This type of dumb bell like pupil is also seen in scyllium

There is a pupillary operculum in the skate and in pleuronectes (sole etc) which swim on their sides near the bottom of the sea the pupil not only closes completely but the upper part hangs over the lower This is possibly analogous to the nodules of pigment (flocculi or corpora nigra) seen at the edge of the pupil of the horse and also to ectropion uveae which is met with as a congenital anomaly in man

In the sauropsida the pupil is often displaced nasally and downwards (corectopia) in the amphibians downwards and in the salamander upwards Gecko has a vertical slit with irregular borders

In some animals the pupil extends beyond the lens so that an aphakic portion is present as obtains after iridectomy in the human This is especially seen in some bony fishes

It would seem that the essential structure of the adult iris in the different species of animals is determined by the embryonic ocular circulation especially the presence or absence of a pupillary membrane and the number and position of the branches of the hyaloid artery The degree of pigmentation and the shape of the pupil however are at any rate in part determined by function or habitat (see Mann *Trans Zool Soc* Part 4 1931)

The Dioptric Apparatus

In the most primitive eyes such as that of the worm *Stylaria lacustris* (Fig 211) the light acts directly on the epithelial cells of which it is composed without first passing through a dioptric apparatus

But soon a rudimentary refractive mechanism appears It may be a simple transparent mass secreted by the epithelial cells or it may be the cuticle covering the eye which becomes thick and transparent or it may be the visual cells them-

selves which become differentiated into bodies refracting the light so as to focus it on the visual cells proper

In the cephalopods there is a cornea lens This consists of two half spheres in contact with each other

A transparent mass the primitive vitreous always fills the cavity of the eye Generally it is secreted by the indifferent cells which lie between the visual cells

In *Phyllodoce laminosa* there is only one of these secretory cells but it is very large (Fig 217)

In the compound or faceted eyes each eye has a small transparent cornea behind which is a cone shaped lens

Vertebrates —*The cornea* is constant in vertebrates It is generally larger in mammals and fishes and relative to the bulb smaller in birds and reptiles larger in nocturnal than diurnal birds

In the cat and rabbit it is one third of the bulb in the bat and mouse one half of the bulb

It is more or less flat in fishes acuminate in nocturnal birds In several species of parrot it forms a keratoconus while it is also prominent in the mole In the whale and seals there is a high degree of astigmatism In the horse it is pear shaped being larger on the temporal side Generally the astigmatism is greater in eyes with an oval or slit like pupil

The corneal epithelium is very thick in fishes and lies almost loose and not smooth as in the human In some terrestrial animals the superficial layers are keratinised Tetrophthalmus swims on the surface of the water with half its cornea out of the water and half in Here only the upper half is keratinised In man the epithelium has 5 layers (Virchow) (6 according to Ciaccio) the horse 20 (Virchow) amphibians 2–4 the ox 8–10 the rabbit 6

In the calf sheep guinea pig chimpanzee and in many birds and fishes the corneal epithelium is so pigmented that this can be seen with the naked eye With the microscope pigment can be found in most corneæ

In some cyprins (gold fish) the cornea is vascularised in others only during embryonic life

In man the cornea is never vascularised except in disease

In fishes and aquatic mammals the cornea is many times thicker at the periphery than at the centre

The substantia propria in the lower vertebrates consists of regular lamellæ throughout In man and the higher vertebrates this obtains in the central area only Elsewhere it is broken up by the fibrous cordage superficially and by elastic fibres in the deeper parts The cornea is a powerful lens but only in those animals which live in the air It loses all its refractive power in water Gullstrand says the cornea in man has a refractive power of 43D and the lens 19D i e more than double

The Lens —Generally speaking as we pass up the vertebrate scale the lens

becomes less and less spherical, but in fishes it is nearly round and often protrudes anteriorly to be almost in contact with the cornea This is due to the fact that the cornea has no refractive power and the lens has to make up for it In amphibians it forms a sphere, but is flattened anteriorly Not infrequently one finds a lenticonus anterior or posterior This is seen especially in the falcon and finch

Among mammals the mouse and rat have a spherical lens In the carnivores the lens is more convex anteriorly, in the herbivores and primates it is the posterior surface which is more convex

As regards size, the nocturnal animals have a large lens, but in the owl it is small In some fishes it is very big (moon fish and whiting)

The nuclear zone in sauropsida (birds and reptiles) develops in a peculiar way to form the soft lens pad This is well developed in the chameleon and lizards and is huge in birds It probably has to do with the amplitude of accommodation

The sutures are Y shaped in man In the selachians they are linear, vertical anteriorly, horizontal posteriorly Birds have no sutures

The general structure of the lens is the same in all vertebrates In some animals (horse) the capsule is very thick and composed of many layers

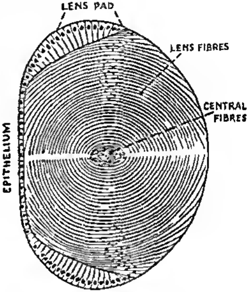


Fig 234 —The Lens of Lacerta (Lizard)
(From Bütschli after Rabl)

Suspensory Apparatus

The lens is held in position by the zonule of Zinn in all vertebrates In birds the zonule, although less extensive, is much stronger than in mammals and much more like a ligament between the lens and the ciliary processes In fishes it is reduced to a triangular band consisting of strong fibres which are attached to the upper pole only of the spherical lens

Fishes and amphibians have muscles in connection with the lens

Fishes have the muscle of the campanule or retractor lentis It runs from the falciform process, and is attached to the back of the lens below and to the nasal side of its centre It pulls the lens outwards and backwards and is associated with accommodation (see p 339)

In amphibians there is a protractor lentis In the urodeles it is a filament which runs from the summit of a ciliary process to the corneo scleral junction It is in relation with the choroidal fissure, and appears to be of ectodermal origin It pulls the lens forwards.

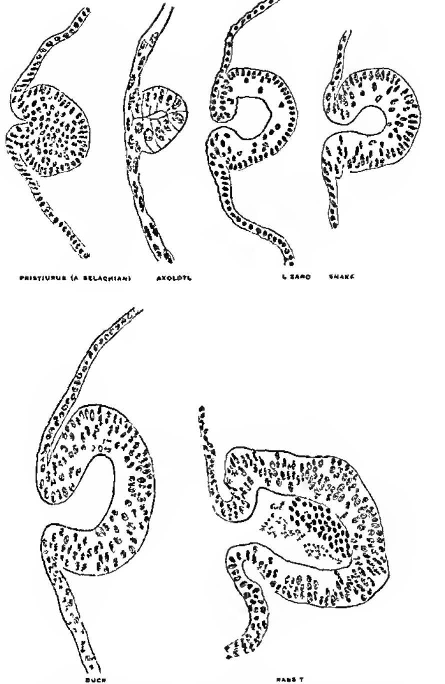


FIG. 235.—THE PRIMORDIUM OF THE LENS AT THE SAME STAGE IN DIFFERENT VERTEBRATES

Note that the débris of cells inside the saccule is found only in the mammal

(From Poll.)

In the frog there are two *protractor lentis muscles, one ventral, the other dorsal.*

In some fishes, too, a retractor lentis arises from the region of the choroidal fissure

Aqueous Humour

In cephalopods the anterior chamber is very large, reaching to the back of the bulb, and since in these animals the cornea is perforate, it is filled with the fluid in which the animal lives

But in those whose cornea is not perforate (cuttle fish octopus) it is filled with a fluid analogous to our aqueous

The anterior chamber is very large in birds and small in fishes In some birds it may be 8 mm deep

In the cat it is 2 5 times greater than in man

The Vitreous

The vitreous is not entirely analogous to the primitive vitreous which fills the eye of invertebrates and which is a simple secretion (see p 340).

Organs of Protection

In fishes the cornea may be considered as such, for, being submerged in water, it takes no part in the refraction of the eye, so also the chitinous cornea of the ocellus and faceted eyes Primitive eyes are protected by their position because they are covered by the epithelium forming the surface covering of the body

Much more protected are the eyes of amphioxus which are found close to the medullary canal

Orbit

The invertebrate eye is more or less buried in ectoderm Only in the cephalopods is there a rudimentary cartilaginous orbit.

The orbit is constant in vertebrates, but varies in size, in completeness, and in the distance apart In relation to the size of the bulb the sea horse (*Trichechus*) has a large orbit, while in the owl the eyes are as it were walled in

In man and monkeys 7 bones go to form the orbit The inferior orbital fissure is narrowest in man and monkeys It is much larger in other vertebrates, so large, in fact, that the outer wall may be absent and then the orbit opens into the temporal fossa and even, in the case of the amphibia, into the pharynx In the horse the superior orbital fissure is a long canal (Nussbaum), and in ruminants, rodents, and some other mammals it is joined to the optic foramen

In man the outer wall is shorter than the inner, while in other vertebrates this wall, although membranous, is the longer.

The two bones always present are frontal and sphenoid The ethmoid, on the other hand, does not take part in the orbit in the common mammals and often the palate does not either

In fishes the *orbital cavity*, much reduced, has accessory bones The frontal is often divided into several parts

In fishes the roof of the orbit is formed by 1 to 6 bones

In pleuronectes (flat fish) the two orbits are asymmetrical and of different sizes When young these fishes resemble ordinary fishes, and have their eyes symmetrically placed Later, when they come to lie on one or other side at the bottom of the sea, the lower eye, which is the left in the sole and the right in the turbot, makes its way through a hole in the frontal bone to come to lie next its fellow They thus have what is known as a *migratory eye*

In the lower vertebrates the lacrimal bone is little developed and really only makes its appearance in reptiles (Kober)

In ornithorhynchus, echidna, the marsupials and edentates it is a simple plate perforated by the nasal canal In the quadrumanes it is limited to the orbit, and does not reach the surface of the face

In the bird, lizard, crocodile and tortoise the orbits are close together In the camel and hare there is one optic foramen for the two orbits In man monkeys, and nocturnal birds the orbits are anterior, in the dog and cat they are slightly lateral In fishes, birds, ruminants and carnivores they are lateral In rodents amphibia, and in some fishes they tend to be above

The relative sizes of eye and orbit are interesting According to Dexler

Pig	I 2 4
Ewe	I 1 6
Goat	I 1 8
Horse	1 3
Ox	I 6

In the elephant the orbit is very large in relation to the eye (Virchow)

An Aponeurosis more or less extensive and containing muscle fibres is present in the orbital cavity These muscle fibres in the frog help to move the bulb and the lower lid, in birds the lower lid only

According to O Burkard this musculature is continuous with the maxillary musculature, which is in direct communication with the orbit, which opens laterally in most vertebrates In amphibians reptiles, and birds, the muscle tissue is striped In the frog, salamander, and lizard it forms real muscles, which are attached to the globe and more especially the lower lid

The more the outer wall of the orbit is closed, the more the tendency for this musculature to be unstriped

Sharks have a cartilaginous peduncle which passes from the back of the globe to the back of the orbit It is expanded anteriorly, and prevents the globe from being drawn back too far—a function taken over in the higher mammals by the capsule of Tenon and the orbital fat

The Sclerotic

In the most rudimentary ocellus the cup of pigment alone forms the outer covering of the eye , but most of the ocelli are surrounded (besides this) by the

basement membrane of the sensory epithelium or even by a connective tissue capsule

A true sclerotic is only present in the vertebrates It is fibrous in mammals, partly cartilaginous, partly bony, in the other classes of vertebrates It is strengthened by a cartilage in birds, reptiles, and fishes, and in some amphibia

Traces are also found in some lower mammals (monotremes) The cartilage has the form of a cup perforated by the optic nerve

In bony fishes and birds (Fig 237, A) the sclerotic is strengthened by cartilage and bone In fishes there are usually two lateral lamellæ of bone, but these may be joined and form a ring (as in the tunny fish and sword fish)

In birds there is a posterior bony cup and an anterior intrascleral ring.

Lids

Lids are only found in vertebrates *Fishes*, owing to the fact that they live in water, have no, or only rudimentary, lids, which are in any case immobile Among the sharks, the lids are more developed The upper is the larger, while the nictitating membrane does the work of the lower (Harman) In *reptiles* there are many varieties of lids

In *chelonians* they are thick and only slightly mobile, in *lizards* thin, and usually only the lower one is mobile In the chameleon they are well developed, but joined so as only to leave a small circular orifice between them

In the slow worm, and other *scinquoidae*, the lower lid is transparent at the centre, and is the only mobile one

It is also transparent in the geckos, but here it is adherent to the upper lid, as in serpents

In the serpent the eye is covered by the lower lid, which is transparent, and forms a " lunette " or window, through which the animal sees Hence arose the idea that the serpent had no lids, and it is also responsible for the " fixed stare " of these animals

In *birds* the lower lid is by far the more mobile

In *amphibians* Maggiore found special glands associated with the upper lid, while the lower lid and nictitating membrane were well developed Lunettes somewhat like that of serpents are found in certain fishes, such as the eel and lamprey, but here the " lids " are not true lids, being a direct continuation of the skin and adherent to the front of the cornea

The Tarsus.—In the higher animals the lids are strengthened by a tarsal plate, consisting not of cartilage but of dense connective tissue Even in the dog it is only slightly marked, in birds and lizards it is only formed in the lower lid, and is entirely absent in the parrot, duck, tortoise, alligator In the iguana and lizard, Elizabeth Cords found traces of hyaline cartilage

The Palpebral Opening varies in size and shape. It is generally relative to the

size of the animal, smaller than the human Only in the elephant is it relatively larger The smallest (relatively) are found in the camel and seal

The Meibomian Glands, which are modified sebaceous glands of the skin, are little developed in other mammals

It has been suggested that they represent a row of lashes which have disappeared in man, but may reappear in the condition of distichiasis when the Meibomian glands are said to be absent

In the camel they appear to be absent (Richiardi, 1816) They are replaced by the sebaceous glands in the huge caruncle of this animal, which fills the whole of the inner canthus

In birds, only traces are found and they have the appearance of sebaceous glands of the skin, with the hairs of which they are still often found associated

Lashes

Lashes are well developed, not only in primates, but also in the dog and pig They are absent in the cat Traces are found in the ostrich and vulture, where they are formed of rudimentary feathers In the horse they are absent in the central portion of the upper lid

Eyebrow.—The eyebrow is found not only in man, but in the higher apes In the cat it is represented by a few long hairs, and in the camel there is a similar formation below the lower lid

The Palpebral Muscles

Lid movements are usually accomplished by the orbicularis and levator palpebræ superioris But in sharks, batrachians, and serpents there is no orbicularis In the elephant there is a depressor palpebræ inferioris (Virchow) In the aquatic mammals there is a muscle in the form of a tube which is distributed all round the lids (Stannius, Virchow), in fact, a dilator rimæ palpebrarum Unstriped muscle was found by H Muller in human lids, and also across the inferior orbital fissure, here mixed with elastic fibres In other mammals it is much better developed, forming an orbital muscle which may act as antagonist to the retractor bulbi All these are supplied by the sympathetic

The orbital muscles are striped in the lower animals, unstriped in the mammal, but appear to have a common origin from the periorbital aponeurosis (Groyer)

The palpebral or tarsal muscles of Muller which are unstriped in man are striped in the aquatic mammals These arise with the recti, which divide into two —a part going to the eye, the other to the lids But in most mammals the lid portion is unstriped

In mammals too, part of the tarsal muscles goes to the nictitating membrane If unstriped they are supplied by the sympathetic, if striped by the nerves that go to the corresponding bulbar muscles

Lashes, unlike ordinary hairs, have no erector pili muscles as a rule, but Zietschmann found traces in the horse and pig

The orbicularis is considered a cutaneous muscle but in man it is independent of the other facial muscles while in lower animals its common origin with these is more evident In the lower animals the orbicularis hardly extends beyond the orbital margin

In birds (Riehl 1908) the orbicularis levator and depressor of the lids are unstriped

The Conjunctiva

The conjunctiva in fishes is cutaneous Lymphoid follicles are present in the calf dog and pig (Marano) The horse has many papillæ

Physiologically no true papillæ or follicles are present in the human conjunctiva although rudimentary forms of both are found

Sweat glands have been described in the bulbar conjunctiva of the goat pig and ox

The utricular glands of Manz at the limbus have been seen in the pig ox lamb and fox and have also been described in man

Visible Pigmentation of the conjunctiva near the corneal margin is present in many animals H Muller found ramifying pigment cells which appeered possessed of remarkable contractile powers

In the Japanese and Chinese (Steiner) the bulbar conjunctiva is always more or less pigmented This pigmentation increases with age and in those who are much exposed to bright sunlight

The Nictitating Membrane, or third eyelid is conjunctival in origin It is best marked in mammals especially the herbivora and in sauropsida and batrachians

Generally speaking one finds this membrane less developed as the hand is more able to wipe the eye (Ovio) Thus it is well developed in the solipeds but less in the cat In man and many monkeys it is absent but some, as for instance the chimpanzee have one In man it is represented by the semilunar fold Usually it is placed at the inner angle of the eye and extends vertically It passes outward somewhat obliquely in front of the eye In the frog and the selachians the nictitating membrane is below and passes upwards in front of the eye like the curtain of the ancient Greek theatre (Hirschberg)

In bony fishes and some others the nictitating membrane is on the temporal side

The nictitating membrane in many animals contains a plate of cartilage which is especially big in the large herbivora Traces of this have been seen in man more especially in the dark races (Giacomini)

Elastic fibres are very abundant in the nictitating membrane The margin is often pigmented and consists of a special band of elastic tissue the limbus marginalis which Kajikawa believes holds the membrane in place without muscular action when in front of the eye as obtains in the tendons of the extremities in birds

In birds and some amphibians such as the frog the nictitating membrane

when stretched becomes transparent in the centre forming a sort of window through which the animal can see

In birds and reptiles but best developed in the former the nictitating membrane is in relation with two special muscles the pyramidalis and the quadratus, which with the retractor bulbi are supplied by the 6th nerve

The quadratus arises from the sclerotic behind the tendon of the superior rectus passes downwards and ends above the optic nerve in a tendinous loop through which the pyramidalis passes

The pyramidalis, smaller than the quadratus arises from the sclera below and passes upwards It ends in a tendon which curves round the lateral side of the

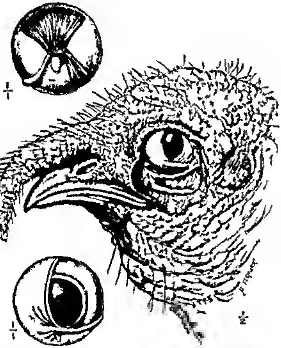


FIG 236.—HEAD OF TURKEY

The insets show the pyramidalis and quadratus also the termination of the tendon in the nictitating membrane The relation of the tendon is also shown in the large figure

(From B and Sutton)

optic nerve then above it to pass through the tendon of the quadratus It continues on and is attached to the nictitating membrane near the inner angle of the eye The membrane may in fact be regarded as the expanded tendon of the pyramidalis In the tortoise these muscles are present but much reduced In the frog the membrane is drawn up by the retractor bulbi muscle In mammals, it has no relation with any muscle Here movement of the membrane is affected by simultaneous retraction of the globe The cartilage which it contains and which is prolonged backwards in the form of a tongue shaped process is in contact with a special mass of orbital fat As the globe passes backwards the membrane is prevented from doing likewise and so it naturally covers more and more of the eye

The Lacrimal Caruncle is found in nearly all mammals, but is almost always larger than in man, and especially so in the camel where it fills the whole of the inner angle of the eye In the dog, the lacrimal caruncle (as in man) contains many accessory lacrimal glands and the deeper layers of the epithelium are pigmented

The Lacrimal Organs

Harder's Gland is found in all vertebrates except the primates It is large in mammals, especially in the herbivora It is rudimentary in the lower apes, but is absent in the anthropoids as in man in whom however, it may be found as a rarity (Giacomini) When the lacrimal gland is well developed Harder s gland is poorly developed and vice versa (Wiedersheim)

Fishes have no lacrimal organs, the eyes being bathed by the surrounding media

The first rudiment of a gland appears in amphibia between the conjunctiva and the skin of the lower lid In the tortoise there is one gland for the two eyes In serpents the lacrimal gland is absent but Harder s gland is very large being placed in the inner angle or sometimes surrounding the globe In certain serpents (thyphlopidæ) it practically fills the orbit, being ten times bigger than the eye, which is rudimentary In birds, also Harder s gland is very big

The Lacrimal Gland

The lacrimal gland and Harder s gland have a common origin in a single gland situated in the lower lid A growth of the medial portion produces Harder's gland, which tends to remain in its original position, while the lacrimal gland tends to move towards the outer canthus, then to the upper lid Its origin from the lower lid is, however seen by some of the ducts which always open under this

Thus the rudiment in the lower lid of amphibia is really the rudiment of both lacrimal and Harder's glands

In the Triton, this rudiment becomes more developed towards the nasal side, and forms a rudimentary gland of Harder Also in this animal a rudimentary lacrimal gland is developed on the temporal side

In birds the lacrimal gland is placed at the outer angle

In the rabbit the lacrimal gland is slightly in the upper lid, but mostly in the lower

The tortoise, unlike other aquatic animals, has a large lacrimal gland situated posteriorly This is due to the fact that the tortoise crosses dry sandy tracts when it wants to lay its eggs, and has to keep its eyes as moist as usual

In the whale the secretion is fatty, like that of the Meibomian glands

In man the lacrimal ducts open on the conjunctiva

In the tortoise, bird, rodent, and lamb the ducts unite to form one, and open in the lower lid

In the primates there are several ducts which open mainly in the upper lid, but some always open under the lower

The lacrimal organs are supplied by the second division of the fifth nerve in all animals up to the mammal In mammals the main supply comes from the first division of the fifth nerve indirectly also from the second

The secretion of the true lacrimal gland is watery that of Harder's oily but in the pig the lacrimal gland is mucous as it is in part in the lamb goat, and dog (Virchow)

According to Wendt the gland of Harder is sebaceous in the lower mammals while it tends to be more like the lacrimal gland as we pass to the higher mammals

The lacrimal gland is in fact a modified skin gland In spelerpes a salamander, it is continuous with these

In serpents which have a large lacrimal gland the ducts open into the mouth —hence the gland is probably salivary in function

The Lacrimal Passages

Generally smaller than in man they are absent in the chelonians (Sardemann) seal hippopotamus and elephant

There is a single passage in the rabbit pig and ewe and double as in man in the other animals

Lacrimal papillæ are only found in man

In the pig the canaliculi lie in bony canals in the lacrimal bone

In the ophidia the lacrimal passages open into the mouth

The Orbital Muscles

Poorly developed in the invertebrates they are well marked in the vertebrates In the invertebrates there are rudimentary muscles in relation to their ocelli

Crustaceans and molluscs have mobile eyes on stalks

Cophilia a phyllopod crustacean has a mobile retina

Daphnia has a single median eye $\frac{1}{10}$ mm in diameter formed by a number of ommatidia This eye is provided with four muscles resembling our recti which keep it in a constant state of vibration and move it in various directions

In vertebrates there are 4 recti 2 obliques and a retractor

The muscles are relatively small in birds and the eye relatively little mobile for the animal moves its head instead

Thus also there is little mobility in fishes reptiles and amphibia except the aquatic tortoise the shark and periophthalmus

In fishes and birds they may be very oblique and often almost at right angles to the optic nerve

In the bony fishes the muscles a short distance from their origin are placed in a canal

The two oblique muscles form an almost complete girdle round the globe In man they are inserted behind the equator In other animals the insertion tends to be in front of this

In most vertebrates, too, they have their origin close together near the front of the orbit. The reflected portion of the superior oblique is thus the original muscle, and is fleshy in many mammals The pulley is developed, as the origin comes to be placed farther back to retain the direction of pull In mammals there is a posterior origin and a pulley

The two obliques cross the recti sometimes between them and the globe, sometimes outside them

In man the superior passes inside, the inferior outside the corresponding rectus In fishes both obliques are outside In birds and in the elephant and chimpanzee, the inferior oblique is outside, but in other mammals usually inside

In the tiger the obliques split to enclose the rectus In the lion only the superior does this

The retractor bulbi (choanoid muscle) is well developed in the large herbivora, but is also found in the tortoise, lizard, and batrachians It is absent in birds and serpents, man, and the higher apes

This muscle, which has the form of a cone, arises at the apex of the orbit and surrounds the back of the globe to the equator It has a tendency to be divided into several portions thus in the whale there are two, and in the batrachians three portions It is supplied by 6th nerve

The main function is to retract the globe It also supports the globe in those animals which hang their heads for hours, and prevents the congestion which would otherwise result In man, Grimsdale thinks this function is taken in by the tonic action of the recti In man, also, this muscle is missing, but Nussbaum found a trace

The Orbital Vessels

In mammals, generally the tendency is for the eye to be supplied by the external carotid, but as we ascend the animal scale more and more comes from the internal carotid

In the dog there are two ophthalmic arteries, one from each source, with an anastomotic branch between them (Parsons and Henderson)

In man the ocular and orbital vessels come from the internal carotid We must not, however, forget the recurrent lacrimal artery, which is an anastomosis between the lacrimal derived from the internal carotid and the middle meningeal, which comes from the external This branch may enlarge and take the place of the ophthalmic, thus reproducing the condition in the lower mammals

A Hyaloid Artery is constant in mammals, but tends to disappear later than in man, and remnants are more commonly found In the cat, for instance,

it remains until one month after birth, and according to Ciaccio, in the mole the hyaloid artery is permanent

The Retinal Vessels—The central vessels always pierce the sheaths of the optic nerve nearer the globe than in man

The Ciliary Vessels are always more important in the supply of the retina than in man, and often the central vessels are so small as to be negligible Indeed, it is disputed whether the dog cat, and fox have an arteria centralis [1]

In the dog we found the retina supplied by cilio retinal vessels only These pierce the *sclerotic* (not the nerve sheaths) and enter the nerve at the level of a ridge of retino choroidal pigment, i e necessarily in the globe

A central retinal vein on the other hand, may be present for a very short distance only, but it also leaves the nerve inside the globe In no case did we see the main retinal vessels cross the subarachnoid space, as they do in man

The depth to which the retinal vessels penetrate into the retina varies In man they go to the outer side of the outer nuclear layer i e just into the outer plexiform layer In the lower animals they penetrate less deeply In the cat, for instance only to the ganglion layer, in the horse and rabbit they are confined to the nerve fibre layer

According to Mann, in rodent embryos the retinal vessels resemble a membrana vasculosa retinæ Later the vessels sink in to become partially embedded in the nerve fibre layer

With regard to the amount of retina which is vascularised, Leber makes the following classification

1 *Holangiotic* (ὅλος = entire)—Entirely supplied by vessels, as in the primates, some insectivores carnivores, ungulates, pig some rodents marsupials, pinnipeds

2 *Merangiotic* (μέρος = partly)—Partly supplied with vessels as in the rabbit and hare The vessels are limited to the areas of the medullated nerve fibres (Fig 231)

3 *Paurangiotic* (παῦρος = small) Slightly supplied with vessels, as in the bat, horse (Fig 230) elephant guinea pig The vessels are very small, and extend only a small distance from the disc

4 *Anangiotic*—The retina contains no vessels, as in the rhinoceros porcupine, echidna

In the agouti a rodent which has a retina almost anangiotic, and in some marsupials there is a cone which is characteristic of the reptiles In the other anangiotic animals, one often finds a capillary vascularisation of the disc which may be visible ophthalmoscopically, and which is analogous to the cone of reptiles or the pecten of birds (Lindsay Johnson, Mann)

[1] Occasionally while at the nerve head no arteria centralis was seen a very small vessel was found farther back in the centre of the nerve (Wolff and Davies *Brit Journ Ophth* November 1931)

The Retinal Vessels

True retinal vessels are found only in mammals

In the lower vertebrates except the eel and a few others the retina is avascular It is the fate of the hyaloid system which determines the final method by which the retina gets its nourishment

The retina may in fact be nourished in four ways (Mann)

1 A completely avascular retina the blood supply being entirely from the choroid (avascular type)

2 An avascular retina associated with a pecten projecting from the optic disc (pecten type)

3 An avascular retina supplied by vessels lying on its inner surface (membrana vasculosa retinæ type)

4 A vascular retina supplied by vessels ramifying in its substance

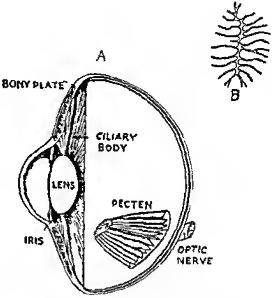


Fig 237 —A = Vertical Section of the *Temporal Half of the Eye of the Ostrich* (Struthio camelus) B Transverse Section of the Pecten

(From Puls

1 *The Avascular Type* (without a pecten or its homologue) is found in many species for instance in certain fishes reptiles and mammals

In the reptiles of this group there is however often a trace of a rudimentary pecten Thus in the crocodile there are a few capillaries and some pigment in the nerve head

Among mammals the avascular retina is seen in the Monotreme (echidna) Edentates (hairy armadillo) Rodents (Brazilian porcupine common guinea pig and chinchilla) Sometimes in ungulates and chiroptera (rhinoceros and Australian fruit bat) (Lindsay Johnson)

Most of these animals have a capillary vascularisation of the nerve head which is visible ophthalmoscopically and a visual acuity which does not reach a high standard

2 *The Pecten Type* is seen in animals of a high degree of visual acuity

The pecten is best developed in birds but it has homologues in the cone of reptiles and the processus falciformis of certain fishes

The Pecten of Birds (Fig 237) is a triangular pleated membrane which extends from the optic disc (and cauda) which it covers forwards for a variable distance into the vitreous It is composed of a loose and folded connective tissue richly supplied with vessels and completely covered with pigment It is this that gives it a velvety appearance

In some birds, such as the swan and duck, it touches the lens, in others, especially in some nocturnal species, it is often rudimentary

The pecten is an ectodermal structure which is secondarily vascularised

The *function* is essentially nutritive, taking the place of the retinal arteries which are absent in birds

Some hold that it has erectile properties, and thus offers a defensive mechanism against too strong light

Kajikawa maintains that the pecten regulates the tension (thus a capillary venous reservoir) the secretion, and the temperature of the eye especially at high altitudes (thus a heat radiator)

The pecten is always attached to the lens although this may in some cases be by very fine fibrils only

The Cone of Reptiles is analogous to the pecten of birds, but instead of being triangular, it is a cone shaped projection from the disc It is well developed in the lizard and chameleon and rudimentary in the tortoise and serpent

It is also ectodermal in origin, being formed by a vascularisation of Bergmeister's papilla which has grown forward into the vitreous

The Processus Falciformis of fishes is a filamentary process which is probably homologous with the pecten It passes from the disc to the back of lens where it spreads out to form an enlargement called the *campanule of Haller* This contains muscle fibres which form an ectodermal retractor lentis muscle

It is also a vascular organ, but covered by epithelium It is derived from the lips of the optic fissure thus ectodermal and is secondarily vascularised

3 *The Membrana Vasculosa Retinae Type* —Here branches of the hyaloid artery spread out over the *surface* of the retina without actually entering its substance Ophthalmoscopically they appear to be retinal vessels, but their true nature is found on microscopic section (Hirschberg)

This type is best seen in snakes but is also found in amphibians (frog) and ganoid fishes (*Amia calva*)

In the embryos of certain rodents a similar condition obtains, while in the adult (white rat) the vessels sink to some extent into the nerve fibre layer, and thus form a link between this and the following type (Mann)

4 *The Arteria Centralis Retinae Type* is typical of the primates It will be remembered that this form of blood supply develops in the first place like the pecten i e by a vascularisation of Bergmeister's papilla But instead of being confined to this, vascular buds grow out into the retina (see p 311)

THE UVEAL VESSELS

The choroidal vessels are much the same throughout the vertebrates, except that in the bony fishes a great thickening of the chorio capillaris posteriorly forms the choroidal gland

The iris vessels however show many variations (see Mann, 1929 and 1931)

In Fishes the iris is usually supplied by two anterior ciliary arteries, which run in the horizontal meridian towards the pupil, round which they form an arterial circle. The venous drainage lies deep, obscured by the silvery membrane (argentea).

In Amphibians, also, the arteries are superficial. They enter the iris at irregular points, and run circumferentially. The veins are deep. Both arteries and veins are often obscured by pigment.

In Reptiles the arteries, inferior and temporal, constantly enter the iris at six and eight o'clock, and then run circularly at the periphery of the iris. Often a superficial set of radial veins is also found.

In snakes, however, there is an irregular network of vessels.

Birds have deep circular arteries with superficial radial veins, and often a dense capillary plexus.

In Mammals only is there a superficial system formed by the pupillary membrane. Hence only in mammals are there direct arterio-venous anastomoses in the region of the lesser circle. The greater circle often lies at the base of the iris, not, as in man, in the ciliary body. Also the ciliary processes tend to be in contact with the back of the iris.

In mammals generally (as opposed to man) the vorticose veins have their exit in front of the equator. Anterior to the vortex veins and not far from the corneo-scleral margin, the ciliary veins form an intrascleral circular anastomosis known as the circle of Hovius (Leber), especially well seen in the seal and porpoise. It drains into the vortex veins, and may replace partly the anterior ciliary veins and the canal of Schlemm.

The Optic Nerve

There is no optic ganglion in the vertebrates, such as is present in the invertebrates (Fig. 221).

In the vertebrates the nerve fibre layer of the retina is directly continuous with the optic nerve.

The form and structure of the optic nerve vary much, depending essentially on the number of fibrous partitions. In some the septa are absent, and then the nerve may be in the form of a ribbon, for instance, in the sword fish and cartilaginous fishes.

In the eel a single partition divides the nerve into two.

According to Deyl, the higher the species of animal the more developed the framework. But Greeff finds many exceptions to this.

The Chiasma

The chiasmal crossing is characteristic of the vertebrates; in Myxinoides, a cyclostome, it is actually in the brain substance. Below the mammal the crossing is complete. In the bony fishes there is a simple crossing, one nerve, usually the right, passing dorsal to the other.

In the herring one nerve passes through the other. In the parrot fish each nerve divides into two, the portions crossing like two fingers of one hand with two of the other (Fig. 238).

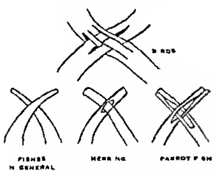


FIG. 238.—THE CHIASMAL CROSSING.
(E.W. after O. fo.)

In most reptiles and amphibians the nerves divide into many portions which, however, cross completely, likewise in birds.

In all mammals except marsupials and monotremes a portion remains uncrossed; as we pass up the scale more and more remains uncrossed. In man about one quarter are uncrossed, i.e. the majority still cross.

The fibres cross to make binocular vision possible.

THE LATERAL GENICULATE BODY

The beginning of a lateral geniculate body is seen in the cyclostomes. It is small in most fishes, but shows better development in the teleosteans (Kappers).

In the amphibians, reptiles and birds it is still small, and does not send any fibres to the cortex (Elliot Smith).

In mammals it reaches its full development. It consists essentially of two nuclei which are dorsal and ventral in the primitive animals. It represents in fact the whole of the lateral geniculate body of the lower animals. As we pass up the scale the dorsal nucleus becomes more important, and the external geniculate body rotates so that what was dorsal becomes lateral. In the primates the ventral nucleus is practically non-existent, and only the dorsal nucleus is cortically represented.

The ventral nucleus receives crossed fibres only, gives off the brachium tecti and is connected with the reflex centres of the mid brain (see Woollard, 1926).

Minkowski showed that enucleation of the eye in man, cats, and monkeys (all having a partial crossing in the chiasma) results in the degeneration of certain layers or zones of both lateral geniculate bodies. He concluded that the crossed and uncrossed fibres go to alternate layers.

In the human external geniculate body, as in that of monkeys, six laminæ are found. The two superficial ones are formed of large, deeply staining pyriform cells, from the deep aspect of which long branching processes arise, while the four deeper laminæ are composed of medium sized cells, triangular and fusiform in shape and fairly closely packed together (see Le Gros Clark, *Brit. Journ. Ophth.*, May, 1932; also p. 246).

PARIETAL AND PINEAL EYES (Figs. 239 *et seq.*)

Parietal and Pineal Eyes are very similar and closely associated.

From the roof of the mid brain two outgrowths may arise.

(*a*) The epiphysis or pineal body, connected with the posterior commissure

(*b*) The parietal or parapineal body, placed anterior to the above and connected with the habenular commissure

Now, while these outgrowths are usually glandular, they may develop into eyes which show more or less differentiation

The Parietal Eye is found in certain saurians (reptiles and birds) It lies under the skin in the parietal foramen, which is analogous to our anterior fontanelle It is a closed vesicle which is connected to the habenular commissure by a band known as the parietal nerve

The eye structure is best seen in the primitive reptiles In the lizard *Lacerta ocellata* for instance, there is a lens and behind it a cavity filled with a liquid like

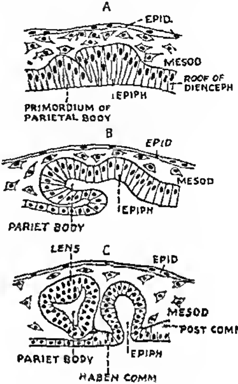


FIG. 239.—THE DEVELOPMENT OF THE PARIETAL EYE AND EPIPHYSIS OF THE EMBRYO LIZARD (LACERTA)

A = embryo of 3 mm section through the roof of the diencephalon showing primordium of epiphysis and parietal organ B = somewhat later C = the parietal organ and epiphysis have separated and the nervus parietalis has formed

(From Bütschli after Nowikoff)

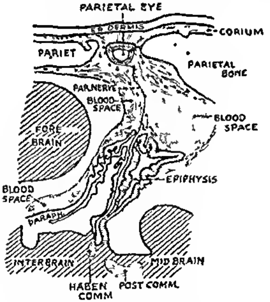


FIG. 240.—MEDIAN SECTION THROUGH THE HEAD AND PARIETAL EYE OF THE ADULT LIZARD (LACERTA AGILIS)

(From Bütschli after Nowikoff)

the vitreous, also a retina in which the rods and cones can be distinguished and a trace of a choroid The pigment it contains has been noticed to move under the influence of light

This eye is poorly developed in the ordinary lizards, it is absent in gecko, and is only *seen during embryonic life in other saurians* In these latter, in fact, the parietal eye disappears more or less completely, it degenerates,

alters and is penetrated by fibrous partitions and vessels which mask its primitive structure and it is in the latter condition that we find the pineal body in all other vertebrates

The considerable size of the parietal foramen in many fossil reptiles makes it probable that in them the parietal eye was of great functional importance the pineal or parietal eye of living species however plays a very small role in vision

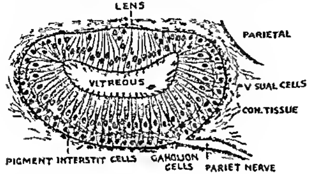
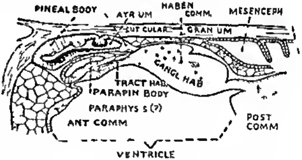


FIG 241 —THE PARIETAL EYE OF THE LIZARD (ANOLIS FRAGILIS)
(From Bütschli after Nowikoff)

The Pineal Eye is much like the parietal The lamprey a cyclostome has both a parietal and a pineal eye

The pineal eye, too is placed under the skin through the transparency of which it is visible It develops from the extremity of the pineal gland and is connected to the posterior commissure by the pineal nerve In it there is a kind of retina with sensory cells and calcareous nodules in place of pigment

FIG 242 —SAGITTAL SECTION THROUGH THE ROOF OF THE FORE INTER AND MID BRAINS OF THE LARVA OF PETROMYZON PLANERI TO SHOW THE PINEAL AND PARAPINEAL ORGANS
(From Bütschli after Studnička)



In elasmobranch fishes the glandular pineal body itself has a bony stalk and is placed in the parietal foramen under the skin In the young frog only a pineal eye is found which degenerates later

It is probable that the pineal gland of vertebrates is derived from paired symmetrical organs which have fused and which correspond to the distal eyes of the salpes (Todaro)

In petromyzon the pineal apparatus is at first paired and symmetrical and later one of these develops into the pineal organ while the other becomes the parapineal or parietal organ which is placed in front of the other (Sterzi)

The 3rd Nerve Nucleus

As we travel up the animal scale the eyes, which at first lie laterally, come more and more to the front of the head We note the same changes ontogenetically in man In the embryo the eyes are first lateral, then later swing round to the front

Associated with these changes we have changes in the appearance of the 3rd nerve nucleus

As the eyes move more and more to the front in phylogenetic history, and as binocular vision is correspondingly more developed and convergence becomes more important, the median nucleus of Perlia is formed, and joins together the originally separate lateral nuclei On the other hand, the nucleus of Edinger-Westphal was originally single and median, and as we pass up the animal scale it tends to divide into two

Thus the nucleus of Perlia is absent in rodents and small in herbivora In carnivora, who have to watch their prey closely it is quite well developed, as also in birds It is especially well developed in the higher apes, and, in man in whom the development of stereoscopic vision goes hand in hand with his mental development, there is a forward prolongation of the nucleus (see Brouwer)

The Edinger-Westphal nucleus, which appears earlier in phylogenetic history than that of Perlia, is single in the cetacea, rodents pinnipedia and carnivora, and paired in the higher apes and in man This may be associated with the fact that when we look at an object which is not equidistant from the two eyes, each eye requires to focus differently to see the object clearly

So far as ontogenetic development is concerned, the nucleus of Perlia is formed when, in the human embryo, the eyes swing round from the side to front of the head, and the nucleus of Edinger-Westphal makes its appearance when the ectodermal portion of the iris is being formed from the margin of the optic cup (Paton and Mann, 1925)

The Dorsal Crossing of the 4th Nerve

The 4th nerve is a motor nerve which arises from a nucleus directly continuous with the 3rd It shows, like all other motor nerves, a central cerebral crossing It differs, however, from them in not remaining on the same side, in not leaving the central nervous system ventral or dorso lateral, and in making a second (almost) complete crossing with the 4th of the opposite side, leaving the brain in an ultra dorsal position before winding round the brain stem to become ventral

It supplies the superior oblique, which in gnathostomes forms the most dorsal muscle (Furbringer)

The ontogenetic history shows that the dorsal position of the nervus trochlearis and superior oblique muscle is acquired very early in embryonic life The superior oblique arises from the dorsal portion of the mandibular myotome

The 4th nerve is already present in the cyclostomes and in all animals there is the curious dorsal decussation

Several theories have been advanced to account for this

It is thought that the 4th nerve was originally sensory (Hoffmann) or motor (Furbringer) to the central pineal eye and when this degenerated it became the nerve to the opposite lateral eye According to Gaskell migration of certain dorsal muscles to supply the lateral eyes can be seen in certain fossil animals

Johnston holds that the 4th nerve leaves the brain dorsally because this is by far the easiest route For otherwise it would have had to pass through the whole thickness of the mid brain

Neal holds that the muscle fibres of the myotome of the second somite which is supplied by the 4th nerve wandered over to the opposite side and with the formation of the head fold acquired a ventral position All the dorsal portion of the myotome degenerated except the superior oblique

The Ciliary Ganglion

The ciliary ganglion is essentially a relay station for the parasympathetic (autonomic) fibres of the 3rd nerve

Sensory ganglion cells (which have wandered from the Gasserian ganglion) have also been described but must be of little importance and the sympathetic certainly has no cell station in the ciliary ganglion

Schwalbe, in fact as the result of extensive researches into its comparative anatomy calls it the *oculo motor* ganglion

He found that in bony fishes amphibians and reptiles the ganglion is connected with the 3rd nerve and in many cases no fibres come from the 5th or sympathetic Also in ganoid fishes (Schreider) in selachians and chelonians (Pitzorno) the ciliary ganglion is associated with the 3rd nerve In mammals the connection with the 3rd is always present although the sensory and sympathetic may be absent as is sometimes the case even in man

Structure —Muller (1920) finds that in the human the cells are exclusively multipolar and different from the sympathetic In birds (Lenhossek and Carpenter) the cells are cerebro spinal in type and the fibres do not divide in a T shaped manner Pitzorno also could find no sympathetic cells in the ganglion

In the equidae the ganglion is microscopic

In the artiodactyls pig boar buffalo goat and in the rabbit the ganglion is double

In birds there is only a motor and no sensory or sympathetic roots These join the ciliary nerves

Experimentally in the dog cat and monkey the ciliary muscle contracts either on stimulating the 3rd nerve or the short ciliaries (Hensen and Voelkers) Destruction of the iris and ciliary body causes degeneration of the cells of the ciliary ganglion

Cauterisation of the cornea causes slight change in the ciliary ganglion and also in the Gasserian ganglion If the ciliary ganglion is painted with nicotine the motor path is blocked while the cornea is not affected This shows an autonomic cell station This experiment could not be repeated in birds in which the ciliary muscle is striated (Langendorf Lodato)

Embryologically —Cells are frequently found migrating along the 3rd nerve to the ganglion and some have also been described coming from the Gasserian ganglion (Carpenter Gafini)

The Brain

As we pass up the invertebrate scale we find a general tendency for the central nervous system to enlarge and become aggregated at the anterior end of the animal

Amphioxus (although classed as a vertebrate really lies between the two big groups) has a simple enlargement in front of the notochord There is no differentiation no true brain formation and no skull is formed round it (hence it belongs to the acrania)

In all other vertebrates the medullary canal divides into three primary vesicles i e the fore mid and hind brain vesicles The first and last of these divide up again so that eventually we have five subdivisions

1 Telencephalon or fore brain
2 Diencephalon or thalamencephalon or inter brain
3 Mesencephalon or mid brain
4 Metencephalon or hind brain
5 Myelencephalon or medulla

The Telencephalon, by a thickening of its roof forms the pallium which later develops into the cerebral hemispheres while a thickening in the floor forms a basal nucleus which will form the corpus striatum of man

In the Diencephalon a thickening at the sides forms the thalamus while the roof remains thin and is often folded

In the Mid-brain the roof forms the optic lobes which in the mammal become the corpora quadrigemina, while the floor forms the cerebral peduncles Since the roof of the mid brain (optic lobes) receives the optic nerve it is known as the tectum opticum

In the metencephalon the cerebellum is developed in the roof while the pons develops in the floor

In the myelencephalon the floor forms the medulla oblongata while the roof remains thin and is often folded

Thus we see that the roof of the diencephalon and that of the myelencephalon remain thin and the vessels with which they are richly provided form the choroidal plexuses Thickenings in the roof of the former however form the ganglion habenulæ and the parietal and pineal organs (*q v*)

We shall now consider shortly how the brain differs in the various groups of vertebrates

In Fishes—We have seen that the central nervous system of amphioxus presents a simple enlargement at its anterior end Some authors hold that one can differentiate the olfactory, trigeminal, and facial nerves but this is doubtful In the selachians the whole of the anterior portion of the brain is olfactory, which is much more developed than the visual portion The optic lobes are however, quite large, and the optic nerve enters them

The pallium is but slightly thickened

In the bony fishes on the other hand the optic lobes are larger than the olfactory part of the brain

The inter brain (diencephalon) is, generally speaking little developed in fishes although there is a small thalamus and geniculate bodies

The cerebellum is very small in cyclostomes small in selachians, and well marked in the bony fishes The medulla oblongata is large owing to the great development of the nerve nuclei especially the 5th, 7th, and the 8th

From the mid brain passes the tecto spinal tract which runs to the posterior longitudinal fasciculus

In Amphibians the olfactory portion is small, the pallium is fairly developed There is a rudimentary thalamus The optic lobes are fairly well developed especially in the anura and the optic nerve goes to them The medulla oblongata is small and so is the cerebellum

In Reptiles the pallium is still further developed and in fact shows the first indication of a cortex which is olfactory There is a rudiment of the corona radiata passing from the basal ganglion to the cortex

The optic lobes are fairly large and in the crocodile there is an indication of a posterior quadrigeminal body The thalamus is fairly well developed, and so are the optic lobes

From the roof of the inter brain the parietal eye is developed

In Birds there is a great development of the roof of the fore brain or pallium to form the cerebral hemispheres The optic lobes are large and the thalamus small The geniculate bodies are fairly well developed The cerebral hemispheres cover a large part of the optic lobes The tractus occipito mesencephalicus unites the occipital cortex with the optic lobes and is the first connection between the eye and the cortex The optic fibres mostly terminate in the optic lobes, but many pass to the geniculate bodies and thalamus

In the pigeon there is a commissure between the optic lobes which may function as a second crossing of the optic pathway Thus, if one removes the left eye and left occipital cortex, the animal will after a time see again which, since there is a complete crossing of the optic nerves may be effected by the tract between the two optic lobes, or, as is more probable, the cortex is associational only (Stefani) (see later, p 363)

In Mammals the striking feature is the great development of the cerebral hemispheres They cover the diencephalon the mid brain and part of the

cerebellum But the mid brain is reduced and the quadrigeminal bodies are smaller than the optic lobes of the lower vertebrates

The inter brain is well developed and so are the thalamus geniculate bodies and peduncles The thalamus becomes a great co ordinating centre for sensory impulses

The olfactory portion varies It is very large in edentates fairly well developed in the carnivora and almost absent in aquatic mammals

The geniculate bodies receive few optic fibres in the lower vertebrates Even in the lower mammals for instance the rabbit more go to the quadrigeminal bodies As we pass up the scale the geniculate bodies receive more and more visual fibres (in man at least 90 per cent)

According to Edinger in those animals in which the visual function is carried out entirely or almost entirely by the primary centres the optic connection with the corpora quadrigemina is large But as cortical vision is developed and perfected the centres closely connected with the cortex take first place namely, the external geniculate body (and the pulvinar) and the part derived from the quadrigeminal bodies lessens in proportion

The pulvinar is little developed in the lower vertebrates compared with what it is in the primates

Up to the sauropsida (birds and reptiles) the roof of the mid brain is not divided into anterior and posterior corpora quadrigemina This change from a bigeminal to quadrigeminal bodies is due to the fact that fibres arising in the cochlea require a separate centre It is first well seen in the amphibians and there is an indication in the crocodile

In lizards each quadrant of the superior colliculus is associated with a definite posture (Wilson 1928) but it is in birds that the optic lobes reach their highest specialisation

The cortex is smooth in edentates and rodents including the rabbit and even some monkeys but it becomes folded in the higher mammals The optic nerves are less developed than in birds

It follows from what has been said above that removal of the cerebral hemispheres in fishes amphibians and reptiles has no effect on vision In birds the real sensory receptive area is in the optic lobes while the cortical centre is associational only Thus if the latter is destroyed visual memory goes but blindness can only be produced by destroying the optic lobes

In conclusion and to some extent summarising what has gone before I would quote from Professor Elliot Smith s Bowman Lecture 1928 [1]

" In all vertebrates the nerve fibres proceeding from the retina cross (wholly or only in part in most mammals) to the other side of the brain where they end in two masses of grey matter—the lateral geniculate body which is part of the

[1] In the *Trans Ophth Soc U K* 1928

thalamus and the superior quadrigeminal body which is part of the mid brain The former connection is concerned with the awareness of vision the phenomena of consciousness and the latter (mid brain) with such unconscious functions as the reflex actions of the eye muscles and the general musculature of the whole body Brouwer has shown that in a lowly mammal such as a rabbit the four quadrants of the retina have a topographical representation in the quadrigeminal body Wilson (of Cairo) has recently demonstrated that the corresponding quadrants in a lizard s brain control definite movements or postures of the body —a kind of autonomous mechanism for the analysis and functional expression of optic influences analogous to the analytic functions of the semicircular canals in connection with equilibration

' In mammals the lateral geniculate body for the first time in the vertebrate series emits a large strand of fibres (optic radiation) to provide a path for visual impulses to the cerebral cortex But the neopallium also begins to assume some of the motor control which hitherto has been a function of the quadrigeminal bodies It is interesting to note that according to Allen this process is not completed in the rabbit Its cerebral cortex according to him controls the movements of the head forelimbs and body but the control of the hind limbs is still retained by the mid brain In most mammals however the transference of motor control to the cerebral cortex is complete

With the acquisition of binocular vision (in mammals such as the cat or better monkeys) the fibres of the optic tracts become rearranged The fibres from the lateral part of each retina no longer cross to the other side of the brain but become connected with the same side so as to bring into connection the terminations of the fibres coming from the medial side of one retina and the lateral side of the other which in binocular vision necessarily act together so as to merge in consciousness the two images of one object

But this rearrangement of the optic tracts necessarily affects the endings of these tracts in the geniculate and quadrigeminal bodies Instead of modification of the retinal localization in the quadrigeminal body to adapt it to the new conditions the cerebral cortex seems more fully to usurp its motor-controlling functions With the loss of such functions the quadrigeminal body al o loses most of the direct connections with the optic tracts and the cerebral cortex acquires a correspondingly enhanced control of the quadrigeminal body

In monkeys and man further profound changes occur in the whole of the visual system A definite macula lutea develops in the retina and each of the percipient cells in the area of acute vision transmits its impulse (indirectly) to a separate fibre of the optic nerve In the rest of the retina and in the retinas of other mammals groups of sensory cells (rods) transmit their impulses into one granule and ganglion cell so that there are far more percipient elements than nerve fibres in the optic nerve Hence when the macula develops in monkeys and man this small area adds a contribution to the optic nerve and tract that is

out of all proportion to its size The macular fibres form more than a third of the optic nerve, and there is added to the geniculate body a new formation as a macular receptive mechanism

"With the atrophy of the quadrigeminal fibres of the optic tract and the sudden increase of the geniculate connection in monkeys and man, practically the whole (more than 90 per cent) of the optic fibres go to the lateral geniculate body But with the enormous increase of the latter the body loses much of its autonomy Its ventral nucleus, which in other vertebrates controlled the quadrigeminal body, atrophies in the Primates In its place the cerebral connection is still further strengthened The geniculate body becomes more and more an intermediary between the retina and the neopallium, and almost the whole function of visual perception becomes concentrated in the cerebral cortex

"The development of macular vision confers upon man the ability to see the world and appreciate its meaning in a way that no other living creature is able to do His new vision depends upon powers of visual perception as distinctive as the use of articulate speech to give expression to what he sees and thinks"

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